UNIVERSITÄT OSNABRÜCK

Unconscious Visual Processing

[PhD Thesis]

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[2012]

Contents

1. Abstract

Visual information can be processed by humans both consciously and unconsciously. Under conscious conditions the humans are aware of the input, and thus can process it according to their goals. However in unconscious conditions participants remain unaware of the input, as evident from their chance accuracy when judging about the input. It has been shown that although participants may not consciously perceive subliminal input, the input can be processed automatically. Masked priming is an experimental paradigm to investigate unconscious visual processing. In this paradigm the input is presented for a very brief duration, often temporally sandwiched between a pre- and a post-mask. In this thesis, I and we mostly applied the masked-priming paradigm to study human unconscious visual processing using words and face images as input. We conducted five studies to understand unconscious visual processing and compare it with conscious processing. Our first study is about the accurate measurement of the visibility of subliminally presented visual input. In the second study, we provide a test-case for the embodied cognition theory using subliminal words. The third study is concerned with conflict control under aware and unaware conditions. In our fourth study, we tried to understand the role of subcortical structures in subliminal face processing. The fifth study is concerned with relations between space and valence priming effects. Together our findings further the understanding of unconscious and conscious visual processing.

2. Introduction

Visual input can be processed both consciously and unconsciously. Unconscious or subliminal visual processing takes place when the human participants remain unaware of the information being presented (Goodale & Milner, 1992; Weiskrantz, Warrington, Sanders, & Marshall, 1974). The masked priming paradigm (Dehaene et al., 1998; Kiefer, 2002; Klotz & Neumann, 1999; Marcel, 1983; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003) is often used to investigate unconscious visual information processing. In this experimental paradigm visual input stimuli, called *primes*, are presented for a very brief duration often sandwiched between a temporally preceding forward mask and a subsequent backward mask. Sometimes only the forward or the backward mask is sufficient to keep primes below the level of the participant's conscious perception. Masked-priming studies have shown that the primes can still affect the processing of subsequently presented visual input called *targets* (because these stimuli are relevant), although the participants remain unaware of the primes. In principle, masked-priming studies consist of two tasks. An indirect measure task in which the effect of the masked primes on subsequent target processing is investigated. Here the preceding masked prime is related to some degree to the target or to the response given to the target, and the priming effect is measured as a performance benefit or cost during the target's discrimination or processing. A benefit occurs when the prime and the subsequent target carry similar information – that is, in a prime-target congruent condition. Similarly, a benefit occurs when the prime indicates a response that is required for the target or associated with the target that is, in the prime-response compatible condition. By contrast, performance costs are incurred when the prime and the subsequent target are incongruent (both carrying ‘opposing’ information) or when the response that is activated by the prime is incompatible with the response that needs to be given to the target. Whether the participants are aware or unaware of the primes in the indirect priming effect measure is often tested in a subsequent direct measure, a prime discrimination task. Here under conditions that are relatively similar to that of the indirect task, participants are asked to discriminate the primes. The invisibility or low visibility of the primes can be established using a participant's hit rates and false alarm rates (cf. Green & Swets, 1966) by calculating Signal Detection Theory’s (SDT’s) visibility index *d’*(d prime), or chi square statistics. As an example consider a study by Marcel (1983). In the indirect-measure task Marcel presented a masked color word as a prime prior to a clearly visible color patch as the target. He asked the participants to report the color of the target. Participants performed faster in naming a prime-target congruent color (e.g., the red color of a target patch after the prime word ‘red’) than a prime-target incongruent color (e.g., the red color of a target patch after the prime word ‘blue’). Although in the direct measure of prime visibility the same participants were unable to discriminate the masked prime words from masked non-words. Related research in this area confirmed that masked primes can directly activate one of the required responses to the targets (cf. Dehaene et al., 1998; Leuthold & Kopp, 1998) and can facilitate processing of a semantically related target (word) as compared to a less related target (cf. Kiefer, 2002). This provides evidence in favor of the dissociation between the processing of the masked primes and their (zero) visibility.

In my first study (Chapter 3), we investigated how prime-target similarity, prime-response similarity, and prime-response mapping variability can influence the visibility measure of the primes. There is an ongoing controversy over how to accurately measure prime visibility. Eriksen (1960) pointed out that empirical dissociations between direct and indirect measures often reflected just a higher difficulty and hence a lower sensitivity of the direct than the indirect performance measure task. For instance, if the direct measure entails a relative difficult task (e.g., the selection among four alternative primes) than the indirect measure (e.g., the selection among two alternative targets), low prime discrimination performance in the direct measure accompanied by a priming effect in the indirect measure could simply result from these task difficulties which are unrelated to the prime’s visibility. Therefore, dissociations based on differences in task difficulty between direct and indirect measures could falsely suggest unaware processing of visual input. This criticism was later on continued and refined (Holender, 1986; Kouider & Dupoux, 2004; Reingold & Merikle, 1988).

We investigated three factors that could potentially influence the sensitivity of the direct measure. Two of these factors, prime-target similarity, and prime-response similarity are by-products of the exhaustiveness criterion – that is, the requirement to keep the conditions of direct and indirect measure tasks as similar as possible (Reingold & Merikle, 1988). The third factor, the variability of the prime-response mapping across experimental trials, concerns the exclusiveness criterion – that is, it is a consequence of the requirement to keep the effects of unconscious processing of the primes out of the direct measure. However, all of these three factors are doubtful in that they might decrease the sensitivity of the prime visibility measure. We found that only the prime-target similarity could potentially affect the sensitivity of the direct measure and that low prime-target similarity improves the direct. This study has been published in a peer-reviewed journal. For details please see Chapter 3 of the following sections.

In our second study we tested the Embodied Cognition Theory (ECT) with subliminal words. When presented subliminally the words can provide a test case for a critical assumption of ECT. According to ECT theory (Barsalou, 1999, 2008; Kaschak & Glenberg, 2000; Kiefer & Spitzer, 2001; Niedenthal, 2007; Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005) semantic representations are stored as general representations of general characteristics of underlying sensorimotor representations. If this assumption holds true, the semantic processing of a word's meaning should be similar to sensorimotor processing underlying its meaning. Neuroimaging studies have shown that word meaning activates brain areas associated with sensorimotor processing (Martin & Chao, 2001). Further, action representations can facilitate the recognition and naming of objects (Helbig, Graf, & Kiefer, 2006; Helbig, Steinwender, Graf, & Kiefer, 2010). Similarly it has been shown that when the meaning of a larger linguistic expression is accessed, a single word can also implicitly elicit an action (Masson, Bub, & Newton-Taylor, 2008). Words can elicit responses on the basis of their long-term meaning (learned through life experience) or short-term meaning (meaning defined by the current task instructions). Until recently, the evidence that processing of the long-term meaning of words supports ECT was restricted to conscious conditions (e.g., Bargh, Chen, & Burrows, 1996; Meier & Robinson, 2004). However, in conscious conditions, the participants could intentionally elaborate the meaning of words. Such intentional elaboration of a word's meaning by imagery of past perception or action during semantically related episodes would not necessarily indicate that sensorimotor representations instantiate semantic representations in an obligatory fashion (Machery, 2007).

Therefore, evidence of sensorimotor effects by a masked word’s long-term meaning would be much more convincing for the assumption that grounding sensorimotor representations are accessed during a word's semantic processing. Thus, a long-term response activation effect that is elicited by subliminal words would provide better evidence for one central tenet of the ECT. We tested this hypothesis in three experiments. In Experiment 1, we tested and found that invisible spatial words as primes led to a congruence effect during the classification of visible targets. In our Experiment 2, we tested and found that the spatial words can indeed elicit responses on the basis of their long-term spatial meaning. Experiment 3 confirmed that subliminal spatial words can also be processed on the basis of their short-term meaning. Thus, our findings support the ECT. This work has been published in a peer-reviewed Journal, for details please refer to Chapter 4.

In our third study we tested whether inter-trial conflict regulation can be observed in the absence of conflict awareness. Human top-down intentions often determine the unconscious effects of primes (Ansorge & Neumann, 2005; Held, Ansorge & Müller, 2010; Schlaghecken & Eimer, 2004). However exerting one's will itself – that is, setting up an intention is considered to critically depend on prior awareness. In the literature (e.g., Greenwald, Draine, & Abrams, 1996; Kunde, 2003), it has been reported that conscious visual perception is a necessary precondition to change one's intention for subsequent visual processing. Researchers found a conflict control in cases where the participants were aware of the preceding conflicting information as compared to an unaware condition. In these studies, participants showed weaker congruence effects after preceding incongruent than congruent trials but only if the primes were clearly visible (e.g., Kunde, 2003). The effect presumably reflects active control that is exerted to shield against the primes if they happened to have interfered with target processing (i.e., in the incongruent conditions; cf. Carter & van Veen, 2007). The fact that this conflict regulation was absent during subliminal priming suggests that top-down control after conflict depended on conflict awareness. This hypothesis was also supported by a neuroimaging study (Dehaene et al., 2003) showing that the brain area associated with conflict control failed to show any significant activity in the unconscious condition (but see Lau & Passingham, 2007). However, there were potentially two caveats in the previous studies which might have undermined the conclusions. First, in prior studies, participants were allowed a longer duration for processing visual conscious input as compared to unconscious input. Secondly, conflict control was based on imbalanced ratios of correctly identified prime trials in the conscious versus unconscious conditions.

To resolve these issues two experiments were conducted. Experiment 1 consisted of a response-priming task including both conscious and unconscious priming conditions. Trial-by-trial analysis revealed the typical conflict control pattern, with reduced priming effects following incongruent rather than congruent primes. However, this pattern was only observed in the conscious condition, although prime processing times in both conscious and unconscious conditions were identical. Also, a similar pattern was observed in a second Experiment, in which the lack of conflict control after unconscious primes was substantiated during correct and incorrect prime-target judgments. Our results suggest that there is no conflict control in the absence of awareness. This work has been published in a peer-reviewed Journal. For details please refer to Chapter 5.

In our fourth study, we investigated the role of subcortical structures in subliminal face processing. It has been shown that humans can process faces unconsciously (Dimberg, Thunberg, & Elmehed, 2000; Kiss & Eimer, 2008; for review see Johnson, 2005; Palermo & Rhodes, 2007) through studies with cortically blind patients (de Gelder, Vroomen, Pourtois, & Weiskrantz, 1999) and healthy humans (e.g., Morris, Öhman, & Dolan, 1999). Similarly Finkbeiner and Palermo (2009) have observed subliminal priming effects in a face gender-categorization task. However, it is still not clear which brain processes are responsible for subliminal face processing. Some authors, for instance, de Gelder et al. (1999), have shown a subcortical origin of nonconscious face processing (see also Pegna, Katheb, Lazeyras, & Seghier, 2005). de Gelder et al. ascribed the capability of their blindsight patient GY's unaware face perception to his intact projection from the retina to the cortex via the midbrain's superior colliculi (SC), just as this has been done for other forms of blindsight (e.g., the ability to use position information affected by the scotoma for pointing; cf. Weiskrantz, 1986; Weiskrantz, Warrington, Sanders, & Marshall, 1974). Consistent with this *midbrain account* of face perception, Jolij and Lamme (2005) found that participants were able to discriminate the emotional expression (sad vs. happy) of subliminally presented schematic faces.

In our psychological experiments, we presented real face images as masked primes slightly peripherally to the eyes and prior to visible target faces and asked our participants to discriminate the gender of the target faces. In five experiments, we varied the visual frequency content of the prime faces, using unfiltered, high-pass filtered (HSF), and low-pass filtered (LSF) face primes. In addition, in all of our experiments we manipulated the direction of attention of our participants either to the target's location or to the prime's location (c.f., Finkbeiner & Palermo, 2009). If the subcortical structures have a role in subliminal face processing, the masked, unfiltered (HSF + LSF) (Finkbeiner & Palermo, 2009) and the LSF face primes should affect the gender discrimination, regardless of where attention had been shifted (i.e., to the target or to the prime). This prediction was based on the known sensitivity of the midbrain's SC for LSF input. However, the masked HSF face primes should not be processed and should not produce a congruence effect. This prediction was based on the known far-going insensitivity of the midbrain's SC for HSF input.

We presented male or a female faces as a clearly visible target. The task of the participants was to press one button for the male, and another button for the female faces. Prior to the target face, we presented a masked face prime in the periphery (cf. Finkbeiner & Palermo, 2009), but either low-pass filtered (LSF) or high-pass filtered (HSF). Hence, we expected that the participants would be unable to report the masked face primes. (This was also ensured in a 2AFC task about the prime gender.) Following Finkbeiner and Palermo (2009), we expected to find a masked congruence effect, where target classification latencies should be shorter for a prime-target congruent (prime and target are of the same gender) condition as compared to the incongruent condition, only by the masked LSF primes. In our two experiments, we consistently found that masked LSF face primes produced a congruence effect and that masked HSF face primes did not. Together our results support the assumption that the subcortical midbrain route which carries the LSF and contains gender-specific features in faces plays an important role during unconscious face perception. This work has been published in a peer-reviewed Journal. For details please refer to Chapter 6.

In our fifth study we investigated space-valence priming with subliminal and supraliminal words. Appraisal processes of humans consist of classifying things and events by either positive or negative valence (Arnold, 1960; Lazarus, 1968; Scherer, Schorr, & Johnston, 2001; Storbeck & Clore, 2007). These processes are crucial for human ontogenetic and phylogenetic fitness (cf. Arnold, 1960; LeDoux, 1998) and an important factor in achieving an individual's vital goals. The processes of appraisal can help in identifying crucial stimulus information and goal-directed actions (cf. Pessoa, Kastner, & Ungerleider, 2002; Posner & Dehaene, 1994). Studies have shown that humans automatically evaluate things and events on a regular basis (cf. Kissler, Herbert, Peyk, & Junghöfer, 2007). These evaluations can also be automatically triggered by irrelevant words. Similarly, studies have shown that unconscious words can also trigger evaluative processing (cf. Galliard et al., 2006; Klauer, Eder, Greenwald, & Abrams, 2007; Naccache et al., 2005; Pessiglione et al., 2007). However, the relationship between appraisal processes and other semantic processing (assessment of meaning in general) is not yet fully understood.

In this study we investigated how quickly the valence, positive or negative, of a word becomes available after presentation. Is it available before or after the semantic meaning of the word is accessed? According to the embodied cognition theory, word meaning is mandatory grounded in more basic sensory or sensorimotor representations (cf. Barsalou, 1999, 2008; Glenberg & Kashak, 2002; Zwaan, Stanfield, & Yaxley, 2002). On the basis of this finding it can be predicted that valence information could only be accessed after some other forms of sensory meaning have been successfully extracted from the word. Here we used an across-category priming effect of sensory representations on valence recognition. The influence of spatial verticality on valence classification task, where spatially high corresponds to positive valence, and spatially low to negative valence, was tested in a subliminal priming paradigm. To understand whether sensory semantics automatically affected evaluations or whether this is the other way round, we used (1) subliminal spatial words as primes and valence words as targets (Experiments 1 and 3), or we used (2) subliminal valence words as primes and spatial words as targets (Experiments 2 and 3). We found that subliminal space prime words influenced valence classification of supraliminal target words (Experiment 1). No influence of subliminal valence primes on the classification of supraliminal space targets into up- and down-words was found (Experiment 2). The final Experiment 3 confirmed that the across-category congruence effect indeed reflected priming of target categorization rather than stimulus-driven response priming. This work has been published in a peer-reviewed Journal. Details about the study can be found in Chapter 7.

References

Ansorge, U., & Neumann, O. (2005). Intentions determine the effect of invisible metacontrast-masked primes: Evidence for top-down contingencies in a peripheral cueing task. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 762–777.

Arnold, M. B. (1960). *Emotion and Personality.* New York: Columbia University Press.

Bargh, J. A., Chen, M., & Burrows, L. (1996). Automaticity of social behavior: Direct effects of trait construct and stereotype activation on action. *Journal of Personality and Social Psychology, 71,* 230–244.

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioural and Brain Sciences, 22,* 577–660.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59,* 617–645.Carter, C. S., & van Veen, V. (2007). Anterior cingulate cortex and conflict detection: An update of theory and data. *Cognitive, Affective, & Behavioral Neuroscience, 7,* 367–379.

de Gelder, B., Vroomen, J., Pourtois, G., & Weiskrantz, L. (1999). Non-conscious recognition of affect in the absence of striate cortex. *NeuroReport, 10*, 3759–3763.

Dehaene, S., Artiges, E., Naccache, L., Martelli, C., Viard, A., Schurhoff, F., et al. (2003). Conscious and subliminal conflicts in normal subjects and patients with schizophrenia: The role of the anterior cingulate. *Proceedings of the National Academy of Sciences USA, 100,* 13722–13727.

Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P., & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature, 395*, 597-600.

Dimberg, U., Thunberg, M., & Elmehed, K. (2000). Unconscious facial reactions to emotional facial expressions. *Psychological Science, 11*, 86-89.

Eriksen C.W. (1960). Discrimination and learning without awareness: a methodological survey and evaluation. *Psychological Review*, *67,* 279–300.

Finkbeiner, M., & Palermo, R. (2009). The role of spatial attention in nonconscious processing: A comparison of face and non-face stimuli. *Psychological Science*, *20*, 42-51.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, *15*, 20-25.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.

Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science*, *273*, 1699-1702.

Helbig, H. B., Steinwender, J., Graf, M., & Kiefer, M. (2010). Action observation can prime visual object recognition. *Experimental Brain Research, 200,* 251-258.

Helbig, H. B., Graf, M., & Kiefer, M. (2006). The role of action representations in visual object recognition. *Experimental Brain Research*, *174*, 221–228.

Held, B., Ansorge, U., & Müller, H. (2010). Masked singleton effects. *Attention, Perception & Psychophysics, 72 (8),* 2069-2086.

Holender, D. (1986) Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: a survey and appraisal. *Behavorial and Brain Sciences*, 9, 1–23.

Johnson, M. H. (2005). Subcortical face processing. *Nature Reviews Neuroscience*, *6,* 766–774.

Jolij, J., & Lamme, V. A. (2005). Repression of unconscious information by conscious processing: Evidence from affective blindsight induced by transcranial magnetic stimulation. *Proceedings of the National Academy of Sciences, 102*, 10747-10751.

Kaschak, M. P., & Glenberg, A. M. (2000). Constructing meaning: The role of affordances and grammatical constructions in sentence comprehension. *Journal of Memory and Language, 43,* 508–529.

Kiefer, M. (2002). The N400 is modulated by unconsciously perceived masked words: Further evidence for a spreading activation account of N400 priming effects. *Cognitive Brain Research*, *13*, 27-39.

Kiefer, M., & Spitzer, M. (2001). The limits of a distributed account of conceptual knowledge. *Trends in Cognitive Sciences, 5,* 469–471.

Kiss, M., & Eimer, M. (2008). ERPs reveal subliminal processing of fearful faces. *Psychophysiology, 45*, 318-326.

Kissler, J., Herbert, C., Peyk, P., & Junghöfer, M. (2007). Buzzwords. Early cortical responses to emotional words during reading. *Psychological Science*, *18*, 475-480.

Klauer, C.-K., Eder, A., Greenwald, A. G., & Abrams, R. L. (2007). Priming of semantic classifications by novel subliminal prime words. *Consciousness and Cognition, 16*, 63-83.

Lau, H. C., & Passingham, R. E. (2007). Unconscious activation of the cognitive control system in the human prefrontal cortex. *Journal of Neuroscience, 27,* 5805–5811.

Klotz, W., & Neumann, O. (1999). Motor activation without conscious discrimination in metacontrast masking. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 976-992.

Kouider, S., & Dupoux, E. (2004). Partial awareness creates the 'illusion' of subliminal semantic priming. *Psychological Science*, *15*, 75-81.

Kunde, W. (2003). Sequential modulations of stimulus-response correspondence effects depend on awareness of response conflict. *Psychonomic Bulletin & Review, 10*, 198-205.

Lazarus, R. S. (1968). Emotions and adaptation: conceptual and empirical relations. In W. J. Arnold (Ed.), *Nebraska Symposium on Motivation* (Vol. 16, pp. 175-26). Lincoln, NE: University of Nebraska Press.

LeDoux, J. (1998). *The emotional brain: The mysterious underpinnings of emotional life*. New York: Simon & Schuster.

Leuthold, H., & Kopp, B. (1998). Mechanisms of priming by masked stimuli: Inferences from event-related potentials. *Psychological Science, 9,* 263-269.

Machery, E. (2007). Concept empiricism: A methodological critique. *Cognition*, *104*, 19–46.

Marcel, A. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology, 15*, 197-237.

Martin, A., & Chao, L. L. (2001). Semantic memory and the brain: Structure and processes. *Current Opinion in Neurobiology, 11*, 194–201.

Masson, M. E., Bub, D. N., & Newton-Taylor, M. (2008). Language-based access to gestural components of conceptual knowledge. *Quarterly Journal of Experimental Psychology, 61,* 869–882.

Morris, J. S., Öhman, A. & Dolan, R. J. (1999). A subcortical pathway to the right amygdala mediating 'unseen' fear. *Proceedings of the National Academy of Science, 96,* 1680–1685.

Palermo, R., & Rhodes, G. (2007). Are you always on my mind? A review of how face perception and attention interact. *Neuropsychologia*, *45,* 75–92.

Pegna, A. J., Khateb, A. Lazeyras, F., & Seghier, M. L. (2005). Discriminating emotional faces without visual cortices involves the right amygdala. *Nature Neuroscience, 8,* 24-25.

Pessiglione, M., Schmidt, L., Draganski, B., Kalisch, R., Lau, H., Dolan, R. J., & Frith, C. D. (2007). How the brain translates money into force: A neuroimaging study of subliminal motivation. *Science, 316*, 904-906.

Pessoa, L., Kastner, S., & Ungerleider, G. (2002). Attentional control of the processing of neutral and emotional stimuli. *Cognitive Brain Research*, *15*, 31-45.

Posner, M. I., & Dehaene, S. (1994). Attentional networks. *Trends in Neurosciences*, *17*, 75-79.

Meier, B. P., & Robinson, M.D. (2004). Why the sunny side is up. Associations between affect and vertical position. *Psychological Science*, *15*, 243-247.

Naccache, L., Galliard, R., Adam, C., Hasboun, D., Clémenceau, S., Baulac, M., Dehaene, S., & Cohen, L. (2005). A direct intracranial record of emotions evoked by subliminal words. *Proceedings of the National Academy of Sciences USA*, *102*, 7713-7717.

Niedenthal, P. M. (2007). Embodying emotion. *Science*, *316*, 1002–1005.

Niedenthal, P.M., Barsalou, L.W., Ric, F., & Krauth-Gruber, S. (2005). Embodiment in the acquisition and use of emotion knowledge. In L. Feldman Barrett, P.M. Niedenthal, & P. Winkielman (Eds.), *Emotion and consciousness* (pp. 21-50). New York: Guilford.

Reingold, E. M., & Merikle, P. M. (1988). Using direct and indirect measures to study perception without awareness. *Perception & Psychophysics*, *44*, 563-575.

Scherer, K. R., Storr, R., & Johnstone, T. (2001). *Appraisal Processes in Emotion: Theory, Methods, Research.* Oxford: Oxford University Press.

Schlaghecken, F., & Eimer, M. (2004). Masked stimuli can bias ‘‘free’’ choices between response alternatives. *Psychonomic Bulletin & Review, 11*, 463–468.

Storbeck, J., & Clore, G. L. (2007). On the interdependence of cognition and emotion. *Cognition & Emotion*, *21*, 1212-1237.

Tamietto, M., & de Gelder, B. (2010). Neural basis of the non-conscious perception of emotional signal. *Nature Reviews Neuroscience, 11*, 697-709.

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. *Proceedings of the National Academy of Science, 100*, 6275–6280.

Weiskrantz, L. (1986). *Blindsight: A case study and implication.* Oxford: Oxford University Press.

Weiskrantz, L., Warrington, E.K., Sanders, M.D., & Marshall, J. (1974). Visual capacity in the hemianopic field following a restricted occipital ablation. *Brain*, *97*, 709–728.

Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Language comprehenders mentally represent the shapes of objects. *Psychological Science*, *13*, 168-171.

3. Sensitivity of Different Measures of the Visibility of Masked Primes

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Journal Publication Citation:

Khalid, S., König, P., & Ansorge, U. (2011). Sensitivity of different measures of the visibility of masked primes: Influences of prime-response and prime-target relations. *Consciousness & Cognition*, *20*, 1473–1488. (DOI: 10.1016/j.concog.2011.06.014)

Abstract

Visual masking of primes lowers prime visibility but spares processing of primes as reflected in prime-target congruence and prime-response compatibility effects. However, the question is how to appropriately measure prime visibility. Here, we tested the influence of three procedural variables on prime visibility measures: prime-target similarity, prime-response similarity, and the variability of prime-response mappings. Our results show that a low prime-target similarity is a favourable condition for a prime visibility measure because it increases the sensitivity of this measure in comparison to a high prime-target similarity.

Introduction

Numerous studies have claimed to demonstrate visual processing of stimuli remaining outside of the awareness of human participants (Goodale & Milner, 1992; Weiskrantz et al., 1974). A very popular experimental approach to demonstrate this dissociation between a lack of visual awareness and an ability to process visual stimuli is the masked priming paradigm (Dehaene et al, 1998; Kiefer, 2002; Klotz & Neumann, 1999; Marcel, 1983; Vorberg et al., 2003). In masked priming, a brief visual prime is presented prior to visual masks at a prime location. As a consequence of the visual masks, the visibility of the prime is substantially reduced, sometimes down to the level of the participants' objective chance identification performance. This is demonstrated in a so-called direct measure of prime visibility, such as a prime discrimination or a prime identification task. The invisibility (or low visibility) of the primes notwithstanding, primes are processed. This is reflected in the so-called indirect measure of priming, for example, in prime-target congruence effects or prime-response compatibility effects. As an indirect measure task, Marcel (1983), for example, presented a masked color word as a prime prior to a clearly visible color patch as a relevant target, and he asked his participants to report the color of the target. Participants were faster in naming a prime-congruent target color (e.g., the red color of a target patch after the prime word 'red') than a prime-incongruent target color (e.g., the red color of a target patch after the prime word 'blue'). This was found although in the direct measure participants were not able to discriminate between the masked prime words and masked non-words. Subsequent research confirmed that masked primes can directly activate one of the required responses (cf. Dehaene et al., 1998; Leuthold & Kopp, 1998) or facilitate processing of a semantically related target (word) in comparison to a less related target (cf. Kiefer, 2002). This amounts to substantial evidence demonstrating dissociations between processing of masked primes and zero visibility of these primes.

There is, however, an ongoing controversy concerning how to accurately measure prime visibility. Eriksen (1960) was probably one of the most influential critics, pointing out that empirical dissociations between direct and indirect measures often simply reflected a higher difficulty and hence a lower sensitivity of the direct than the indirect performance measure task. For instance, if the direct measure uses a more difficult task (e.g., the selection among four alternative prime words) than the indirect measure (e.g., the selection among two alternative target words), low prime discrimination performance in the direct measure accompanied by a priming effect in the indirect measure could result from these task difficulties that are unrelated to prime visibility. Therefore, dissociations based on difficulty differences between direct and indirect measures cannot demonstrate processing of visual stimuli in the absence of awareness. This criticism was later repeated and refined (Holender, 1986; Kouider & Dupoux, 2004; Reingold & Merikle, 1988). Reingold and Merikle (1988) distinguished between two characteristics which they considered to be especially important for the quality of the direct measure, namely its exhaustiveness and its exclusiveness. A direct measure is considered to be exhaustive with respect to measuring a particular stimulus, feature, or information if the measure is sensitive to any consciously perceived change or facet of this stimulus, feature, or information. In addition, a direct measure is said to be exclusive with respect to the visibility of a particular stimulus, feature, or information (or the participant's awareness about it), if the direct measure is not sensitive to any change of this stimulus, feature, or information that does not reflect the visibility of this stimulus, feature, or information (or the participant's awareness about it) (cf., Reingold & Merikle, 1988). These concepts are summarized in Figure 1.

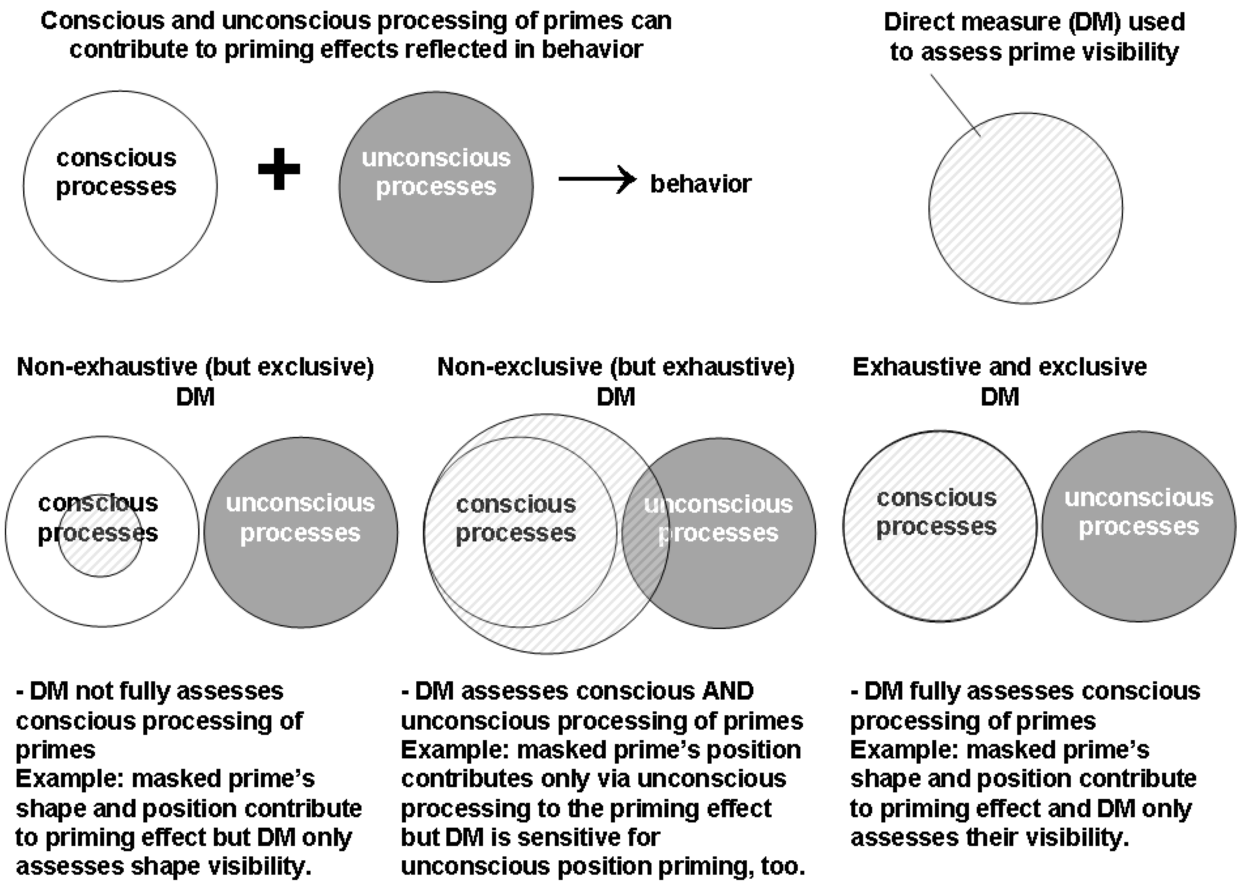


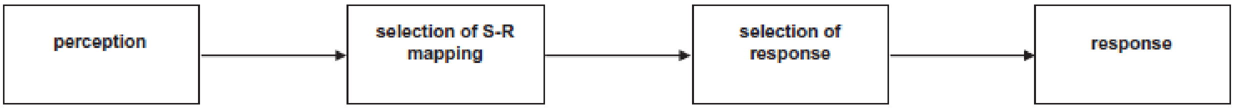
***Figure 1**:* Upper left: Conscious as well as unconscious prime processing can contribute to a priming effect in behavior. Upper right: A direct measure (DM) is illustrated as a hatched area. A DM must be used to assess the possibility that conscious prime processing contributed to the priming effect. Lower left: A DM that does not assess the participants' awareness of all potentially contributing prime features is non-exhaustive (but can be exclusive, as illustrated). Lower central: A DM that is sensitive to unconscious prime processing is non-exclusive (but can be exhaustive, as illustrated). Lower right: A DM that assesses all potentially contributing prime features and at the same time is insensitive to the unconscious processing of the prime is both exclusive and exhaustive.

Crucially, Reingold and Merikle (1988) argued that researchers should ideally use an exhaustive direct measure of the conscious information of the primes that needs to be at least as simple as the indirect measure, and researchers should therefore keep the conditions in the direct and the indirect measure task as similar as possible (see also Schmidt & Vorberg, 2006).

Yet, for an exhaustive direct measure of the conscious information of the primes, researchers might be urged to sacrifice the exclusiveness of the direct measure with respect to the unconscious information of the primes. A direct measure of the conscious information of the primes is considered exclusive with respect to the unconscious information of the primes if it only reflects the visibility of the prime but not the awareness-independent processing of the prime. Assuming that aware and unaware processing potentially both contribute together to any visual effect (cf. Jacoby, Toth, &

Yonelias, 1993; Schmidt & Vorberg, 2006), attempts to exhaustively measure the visibility of a masked prime with the most sensitive methods could also tap into and, thus, reflect visual processing without awareness (Reingold & Merikle, 1988). As a consequence of the importance of these methodological issues, many studies have investigated the factors that impact on prime visibility measures, such as the visual feature that needs to be discriminated or the practice with the discrimination task (Ansorge, Becker, & Breitmeyer, 2009; Ansorge, Breitmeyer, & Becker, 2007; Klotz & Neumann, 1999; Kouider & Dupoux, 2004; Schubö, Schlaghecken, & Meinecke, 2001; Wolford, Marchak, & Hughes, 1988).

The present study investigated three factors that might influence the sensitivity of the direct measure. Two of these factors, (1) prime-target similarity and (2) prime-response similarity are a consequence of the exhaustiveness criterion and of keeping the conditions of direct and indirect measure tasks as similar as possible, while the third factor, (3) the variability of the prime-response mapping across trials comes into play to meet the exclusiveness criterion of the direct measure. However, all three factors correspond to a potential source of confusion that might decrease the sensitivity of a prime visibility measure. This will be explained next and is also summarized in Figure 2.



stage	principle	necessary side conditions	example of an error
perception	prime-target confusion	prime-target similarity (e.g. primes are the words 'up' and 'down' and targets are also the words 'up' and 'down')	participant erroneously confuses an 'up' target in an incongruent trial with a preceding 'down' prime
selection of S-R mapping	confusion between different mappings	use of varying S-R mapping (e.g. prime word 'up' requires a right hand key press according to mapping 1 but a left hand key press according to mapping 2)	participant erroneously responds according to mapping 1 when mapping 2 applies
response selection	confusion between long-term and short-term response meaning	use of short-term response mapping at variance with the prime's long-term meaning (e.g. prime word 'up' requires a downward response)	participant erroneously gives an upward response to an 'up' prime when instructions require a downward response to this prime

Figure 2: Depicted is a sequence of processing stages during prime discrimination together with a table in which the stages are linked to their particular sources of erroneous prime judgments, plus examples of the corresponding errors. S-R: Stimulus-Response.

Concerning influence (1) – the overall similarity between masked prime and visible target –, in many direct measures of prime visibility, visible targets were very similar to the masked primes (e.g., Kiesel, et al., 2009; Neumann & Klotz, 1994; Schmidt, 2002; see also Table 1). For example, Ansorge and Neumann (2005) used the same kinds of stimuli (small bars) as masked primes and as targets. This high prime-target similarity could lead to more confusion of masked primes with visible targets than the use of targets that are more different from the primes (cf. Duncan & Humphreys, 1989) if the visibility test requires reporting of the primes but not the targets. The reason for using confusable primes and targets in the direct measure is that these conditions are also used in the indirect measure. In the indirect measure, the priming effect is often determined as a congruence effect – that is, as better performance in congruent conditions (with primes being similar to the target in the same trial) than in incongruent conditions (with primes being dissimilar to the target in the same trial). Keeping this kind of orthogonal identities of masked prime and visible target across trials also in the direct measure task, the confusion of prime and target should decrease the performance in incongruent conditions: In the incongruent condition, occasional confusion between prime and target should lead to the erroneous report of the wrong stimulus. In line with this possibility, a larger number of erroneous judgments about the masked prime in incongruent than congruent conditions has indeed been occasionally observed (e.g., Schmidt, 2000). This disadvantage could be either due to the above-mentioned confusion of prime and target or to a bias to respond with the target's identity if the prime happens to be barely seen and the target fits within one of the to-be-discriminated categories for the judgment concerning the prime (cf. Vorberg et al., 2004). In any case, the disadvantage is always a direct consequence of the researchers' attempt to keep direct and indirect measures equally simple and as similar as possible, that is, a consequence of the necessity to meet the exhaustiveness criterion.

Concerning influence (2) – the similarity between prime and response –, a confusion of the prime's 'true' or long-term meaning (i.e., its meaning as acquired in the 'real life' outside of the experimental context) with its short-term response meaning as experimentally defined in the direct measure task can also decrease performance in this task. This happens if the long-term meaning of the prime is opposite to the direct measure task's short-term response meaning of the prime. This could have compromised the sensitivity of some visibility measures, too (see Table 1). Neumann and Klotz (1994), for example, presented a pair of masked prime figures. In some trials, the prime pair consisted of one square and one diamond, with one of these figures left and the other one right of fixation. In this situation, the screen position of a specific to be searched-for prime figure (e.g., of the square), as being left or right, defined this prime's spatial long-term meaning. Importantly, however, in the visibility tests of these studies, spatial short-term response meaning of the to-be-reported masked prime was sometimes the opposite of their long-term meaning. The direct measure task of the participants was to discriminate conditions with a searched-for prime figure (e.g., with a square) by pressing one button (e.g., the left one) from neutral conditions, without a searched-for prime figure (e.g., with a prime pair consisting of two diamonds) by pressing the other button (e.g., the right one).

Thus, the prime's short-term response meaning (e.g., a left response) and its long-term meaning (e.g., its right position) were sometimes the same or spatially compatible but on other occasions they were opposite to one another or incompatible (cf. Fitts & Seeger, 1953). In the spatially stimulus-response (S-R) compatible condition, for instance, the searched-for square prime would have been on the right and a right response would have been required for the report of a square-shaped prime. As a consequence, spatial long-term meaning conveyed by the square prime's position could have activated and ensured the finally required response in the direct measure (cf. Kornblum, Hasbroucq, & Osman, 1990; Zhang, Zhang, & Kornblum, 1999). However, under spatially S-R incompatible conditions, the long-term meaning of the prime's position corresponded to the alternative required response. As an example, let us again assume that the detection of a square prime required a right button press and the absence of the square required a left button press. By presenting the square prime on the left, the spatial long-term meaning of the square prime's position could then have activated an incorrect response in comparison to its short-term response assignment in the direct measure task (cf. De Jong, Liang, & Lauber, 1994; Lu & Proctor, 1995) and, hence, lowered the sensitivity of this measure by means of a confusion between the prime's long-term spatial meaning and its short-term response meaning. Again, this source of confusion is a consequence of the researcher's goal to keep the conditions in both tasks (direct measure task and indirect measure task) as similar as possible.

Table 1. Non-exhaustive overview of the masked priming studies in which visibility tests for masked primes were prone to prime-target confusion (column P-T [Prime-Target confusion] possible?) or to the confusion of the prime's long-term meaning and an alternative short-term response meaning (column P-R [Prime-Response confusion] possible?).

Study		**P-T possible?**	**P-R possible?**
Abrams et al. (2002)		yes	no
Abrams & Greenwald (2000)		yes	no
Albrecht et al. (2010)		yes	no
Ansorge et al. (2007)		yes	yes
Ansorge et al. (2010)		yes	yes
Ansorge & Neumann (2005)		yes	yes
Breitmeyer et al. (2007)		yes	no
Chen & Treisman (2009)	Exp. 1	no	yes
Cressman et al. (2006)		yes	no
de Gardelle & Kouider (2010)		yes	no
Dehaene et al. (2004)		yes	no
Dehaene et al. (1998)		no	yes
Draine & Greenwald (1998)	Exp.4	yes	no
Finkbeiner & Palermo (2009)		yes	no
Greenwald et al. (1996)		yes	no
Greenwald et al. (2003)		yes	no
Hirshman & Durante (1992)		yes	no
Jaśkowski et al. (2002)		yes	yes
Jaśkowski et al. (2003)		yes	yes
Kiesel et al. (2006)		yes	no
Kiesel et al. (2009)		yes	no
Klotz & Neumann (1999)		yes	no
Klotz & Wolff (1995)		yes	no
Kouider & Dupoux (2004)		no	yes
Lau & Passingham (2007)		yes	no
Marcel (1983)		no	yes
Mattler (2003)		yes	no
Mattler (2006)		yes	no
Mattler (2007)	Exp. 2 +3	yes	no
Merikle & Joordens (1997)		no	yes
Naccache & Dehaene (2001)	Exp. 2	yes	no
Naccache et al. (2002)		yes	no
Neumann & Klotz (1994)		yes	yes
Pohl et al. (2002)		yes	no
Przekoracka-Krawczyk, & Jaśkowski (2007)		yes	yes
Schmidt (2002)	Exp. 1	yes	no
Schmidt et al. (2006)		yes	no
Tapia et al. (2010)		yes	no
Vath & Schmidt (2007)		yes	no
Vorberg et al. (2003)	Exp2 + 1d	yes	no

Concerning influence (3) – the confusion between mappings –, at least some masked priming experiments used variable prime-response mappings (cf. Ansorge et al., 2007, 2009) while others used fixed prime-response mappings (e.g., Klotz & Wolff, 1995; Neumann & Klotz, 1994). The selective use of variable S-R mappings in the direct-measure task but not in the indirect-measure task creates a difference between the direct and indirect measure task, diminishing the similarity of these two tasks and therefore counteracting the exhaustiveness of the direct measure. Variable mappings are sometimes used nonetheless to prevent an undue (boosting) influence of unaware processing of the primes on the performance in the visibility task. The reason is that studies of Neumann and Klotz (1994) suggested that one crucial prerequisite of awareness-independent motor activation by a masked prime is that participants have prior knowledge of the required stimulus-response mapping (see also Damian, 2001; Kunde et al., 2003). The underlying cognitive processing principle has been termed 'direct parameter specification' and it requires the participant's full articulation of an action plan for an unaware stimulus to activate a response (cf. Neumann, 1990). By varying the prime-response mapping between trials and informing the participants about the mapping only after the prime in the direct measure task, researchers can prevent participants from fully articulating their action plan: Participants simply do not know which response is required to the upcoming stimulus. Thereby, researchers can prevent that unaware response activation contributes to the performance in the visibility measure.

However, even with a supraliminal stimulus presented above the threshold of aware perception, the use of varying stimulus-response mappings can lower stimulus discrimination performance in comparison to the use of a fixed stimulus-response mapping that applies throughout each trial of an experiment (cf. Schneider & Shiffrin, 1977). One reason is that with varying S-R mappings, participants sometimes press the wrong key because they confuse the mappings with one another and apply an actually incorrect S-R mapping. If that happens in a prime visibility test, it should lead to lower prime detection or discrimination performance in conditions with a variable mapping than with a fixed mapping.

There are thus good reasons to assume that variation of prime-response mappings across trials, a low compatibility between the prime's long-term meaning and the required responses, and a high overall prime-target similarity can lead to a lower sensitivity of the direct measure, but the widespread use of prime-target similarity in prime visibility tests alone (see Table 1) indicates that awareness among researchers of these critical issues is low.

The current study seeks to fill in the missing information and to assess whether the above mentioned variables indeed are problematic. Between Experiments 1 and 2, we varied the prime-target similarity and tested whether better prime discrimination performance is found with a low than with a high prime-target similarity. In both experiments, we also compared within participants whether prime detection performance was better with a fixed than with a variable mapping. Finally, we tried to determine whether prime detection performance is better in S-R (here: prime-response) compatible than incompatible conditions.

Experiment 1

In Experiment 1 we tested whether discrimination of a masked word prime is better with a fixed than with a variable prime-response mapping. To note, we kept the terminology of the masked priming literature. We refer to the masked words as primes and to the visible words at the end of the trials as target dummies, because they had the position of a target word in a standard prime-target sequence. Here, however, they were in fact never used as targets. Instead, we only took direct measures of prime discrimination.

In some of the blocks, the prime-response mapping was fixed and in others the prime-response mapping varied from trial to trial in a pseudo-random sequence. If participants occasionally confuse the actually applicable mapping with the alternative mapping, we should find lower prime discrimination performance in variable than fixed mapping conditions.

We also investigated whether participants confused the prime's long-term meaning with its short-term response meaning. To that end, we used four different direct measure tasks (in separate blocks) for each of our participants. In all tasks, we asked the participants to report the spatial meaning of the masked prime words. Participants had to press one key for an up prime (e.g., the masked word 'above') and another key for a down prime (e.g., the masked word 'below'). With a highly compatible fit between the prime's long-term meaning and the required response, an up prime required an upward response, and a down prime required a downward response. With a neutral fit between the prime's long-term meaning and the required response, an up prime required a left response and a down prime required a right response (or vice versa). In the neutral condition, based on Cho and Proctor's (2003) orthogonal compatibility effect, up primes mapping on right responses and down primes mapping on left responses could be considered to be slightly more compatible than down primes mapping on right responses and up primes mapping on left responses. Finally, with a low-compatible fit between the prime's long-term meaning and the response, an up prime required a downward response and a down prime required an upward response.

If it is true that participants sometimes confuse the actually required instructed response with the long-term meaning of the prime, we should find a lower prime discrimination performance in the low-compatible conditions than in the highly compatible conditions, with the performance in the neutral condition lying in between (plus maybe an advantage for neutral conditions with an orthogonally compatible mapping as compared to neutral conditions with an orthogonally incompatible mapping).

Finally, in Experiment 1, prime-target similarity was high. The same set of words was used as primes and targets. Across trials, prime identities and target identities varied orthogonally with respect to one another. As a consequence, we were able to test whether participants confused prime and target identities. This should show up as better prime discrimination performance in congruent trials, in which prime and target belonged to the same response-category of words (e.g., the prime word 'above' before the target word 'up') than in incongruent trials, in which prime and target belonged to alternative response-categories (e.g., the prime word 'above' before the target word 'down').

Method

Participants. Twenty-seven students (18 female) with a mean age of 22.5 years participated in Experiment 1a, and another 10 participants (8 female) with a mean age of 21.9 years participated in Experiment 1b. Here and in Experiment 2, all participants had normal or corrected to normal vision. They were either paid 5 € per hour or received course credit.

Apparatus of Experiments 1a and b. The experiment was performed on a Macintosh computer, with a 15-inch flat color display. The refresh rate was 59.1 Hz. Responses were recorded via four number keys of the numeric keypad of a standard computer keyboard. Each trial started by the participant's pressing of key #5 in the center of the number block. The other response keys were located above (key #8), below (key #2), right (key #6), and left (key #4) of key #5, respectively. Participants put their index finger on the central 'home' key and pressed it to start each trial. The participants sat at a distance of 60 cm from the screen in a quiet, dimly lit room, with their head resting in a chin rest to ensure a constant viewing distance and a straight-ahead gaze direction.

Stimuli and procedure of Experiment 1a. We increased the variance of the prime discrimination performance by use of a relatively weak form of masking. This was achieved by using a pre-mask of 30 ms and, thus, of considerably shorter duration as compared to optimal masking conditions (e.g., 200 ms; cf. Kiefer & Brendel, 2006).

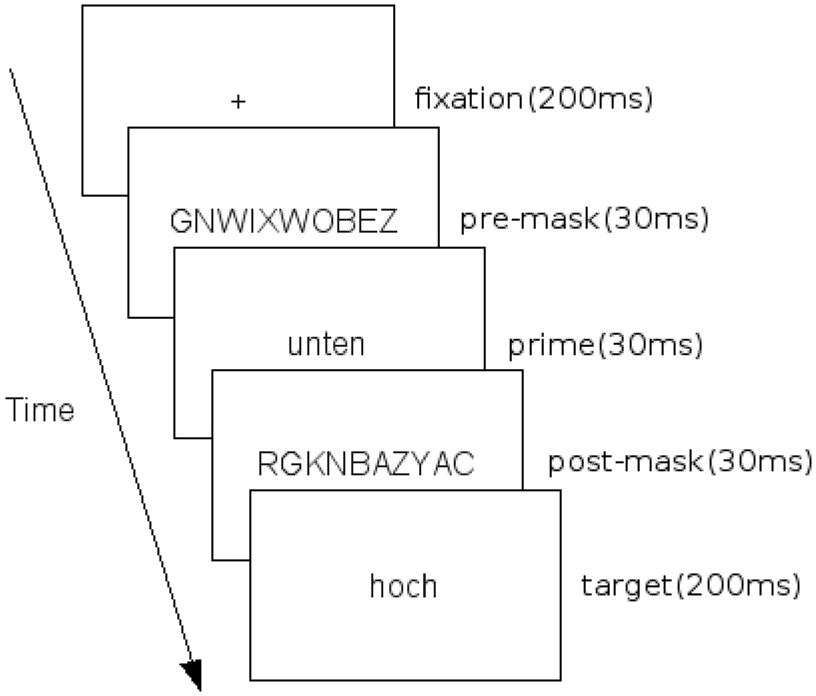


Figure 3: Depicted is a sequence of stimuli in an incongruent trial of Experiment 1a & 1b.

See Figure 3 for an example of a sequence of events in a trial. Stimuli were presented in black (luminance < 0.1 cd/m2) on a grey screen (luminance = 120 cd/m2). A trial started with a screen fixation mark (a plus sign) in the screen centre for 200 ms. Next a mask consisting of 10 capital letters was shown in the centre of the screen. The letters (font size of 40 pixels; Arial script) were chosen at random from the alphabet, and stayed on the screen for 30 ms. After the mask one prime word was shown at screen centre. The prime word denoted a spatial position 'above' or 'below'. The masked prime words were randomly chosen from the set of German words 'abwaerts', 'herab', 'hinab' (all three meaning 'downwards'),'sinkend' ('sinking'), 'darunter', 'unten' (both meaning 'below'), 'gesenkt' ('lowered'), 'niedrig' ('low'), 'tief' ('deep'); and 'aufwaerts', 'hinauf', 'aufsteigend', 'empor' (all four meaning 'upwards'), 'darueber' ('above'), 'steigend' ('increasing'), 'hoch' ('high'), 'oben' ('up'), 'gestiegen' ('increased'), and 'erhoeht' ('lifted'). The set of words thus consisted of twenty prime words, ten words denoting 'up' positions and the other ten denoting 'down' positions on the vertical axis. The prime word was presented for 30 ms. After the prime word a second mask was displayed for 30 ms at the same location. It also consisted of 10 capital letters that were drawn at random and independently from the prime-preceding mask. After the second mask a clearly visible second word was shown for 200 ms. This second word took the place that would usually be occupied by the visible target in an indirect measure of priming. These target dummy words were chosen from the same set of words as the primes. Target dummy and prime words were orthogonally combined with two constraints, (1) congruent (spatial prime word meaning = spatial target dummy word meaning) and incongruent (spatial prime word meaning ≠ spatial target dummy word meaning) conditions were equi-probable, and in no trial the prime word and the target dummy word were exactly the same.

Participants had to report the spatial meaning of the masked prime words. In half of the blocks, participants had to press one key below and the other key above the home key to report the different spatial meanings of the prime words (up vs. down), and in half of the blocks, participants had to press one key to the left and another key to the right of the home key to report the two different spatial meanings of the prime words. Separated blockwise, the prime-response mappings were either fixed and specified in advance of the whole block, or the prime-response mappings varied in a pseudo-random sequence across trials. Only in the latter blocks, an instruction display was shown after the visible target dummy word telling the participants how to respond to the different possible meanings of the actual prime word. Table 2 gives an overview of the different possible conditions.

Table 2. The different possible primes (Up; Down) and responses (upward = ↑, downward = ↓; rightward = →, leftward = ←) and their compatibility relation as a function of the S-R mapping types; each participant received two blocks (two out of blocked conditions 1-4 below) with fixed mappings, one with up and down responses (one out of blocked conditions 1-2 below) and one with left and right responses (one out of blocked conditions 3-4 below), and two blocks with variable mappings (blocked conditions 5 and 6). The compatibility of the fixed mappings, the sequence of blocks (up and down responses first; left and right responses first; fixed mappings first; variable mappings first) were balanced across participants.

Condition	**Prime**	**response**	**compatibility**	**mapping**
1	Up	↑	compatible	fixed
	Down	↓		
2	Up	↓	incompatible	fixed
	Down	↑		
3	Up	→	neutral	fixed
	Down	←		
4	Up	←	neutral	fixed
	Down	→		
5	Up	↑	compatible	variable
	Down	↓		
	Up	↓	incompatible	
	Down	↑		
6	Up	→	neutral	variable
	Down	←		
	Up	←	neutral	
	Down	→		

Each block started with a general instruction informing the participants about the possible prime-response mappings and whether one mapping or two mappings applied in the upcoming block. In fixed mapping blocks, they were instructed to press one key for one type of primes and the alternative key for the other type of primes, depending on the block and with different possible mappings balanced across the participants. In variable mapping blocks, the participants were instructed to respond according to the mapping instructions at the end of each trial. The different mappings were pseudo-randomized and balanced within each block. It was also carefully explained to the participants that the visible targets were irrelevant for the task and that the spatial meaning of the target words was equivocal regarding the spatial meaning of the prime words. Half of the participants started with alternative vertical responses, the other half started with alternative horizontal responses.

Which of the two possible prime-response mappings applied in the blocks with a fixed mapping was balanced across participants, half of the participants were responding compatibly (fixed up/down responses, i.e., FUD) or orthogonal compatibly (fixed left/right responses, i.e., FLR) and the other half was responding incompatibly or orthogonal incompatibly. In variable mapping conditions, however, the compatibility or orthogonal compatibility was varied within participants, as the instructions were varied from trial to trial. Due to these variations the design of our ANOVA was initially not fully factorial in Experiment 1a.

Each block consisted of a total of 250 trials including the first 10 as training trials. Responses for training trials were not recorded and the participants were informed about the start of the actual experiment after the training trials finished. The experiment was run in a single session, and two short breaks were provided, one in the middle and one at the end of each block. The whole experiment took around 60 – 70 minutes to complete.

Stimuli and procedure of Experiment 1b. To assess the impact of the variables on the performance in the direct measure, we originally only compared the performance measures from different blocked conditions with chance performance. However, to also run an ANOVA including all variables, compatibility, congruence, and mapping at the same time, the unbalanced design in Experiment 1a was disadvantageous1. Therefore, Experiment 1b repeated the procedures of Experiment 1a but with a fully factorial design. Every participant worked through altogether six blocks, four with a fixed mapping (FUD/compatible mapping; FUD/incompatible mapping; FLR/compatible mapping; and FLR/incompatible mapping) and another two with a variable mapping (one with left vs. right, and one with up vs. down responses). In this design, the different conceivable block order positions were balanced across participants by a latin-square procedure, with the constraint that either all fixed mapping blocks were run at the beginning of the experiment or all fixed mapping blocks were run at the end of the experiment. The participants took about 90-120 minutes to complete the experiment.

Results of Experiment 1a

Prime visibility was assessed using Signal Detection Theory’s (SDT’s) visibility index d’. d’s were obtained from direct calculation of hit rates and false alarm (FA) rates (cf. Green & Swets, 1966). Here correct responses to ‘up’ primes counted as hits and wrong responses to ‘down’ primes as false alarms (i.e., ‘up’ primes were taken as ‘signals’, and ‘down’ primes as ‘noise’). d’ is the z-transformed FA rate subtracted from the z-transformed hit rate. This index becomes zero in the case of chance performance and it can infinitely increase with ever increasing discrimination performance.

The individual hit and FA rates of each participant for the six different mappings can be seen in Figure 4 which plots sensitivity (or hit rate) as a function of ‘1 - specificity’ (or false alarm rate). The plots show a higher average sensitivity for congruent conditions (square symbols) than for incongruent conditions (spool-shaped symbols). To confirm the impression, for each different combination of the steps of our independent variables, we conducted t tests of d' against zero in turn.

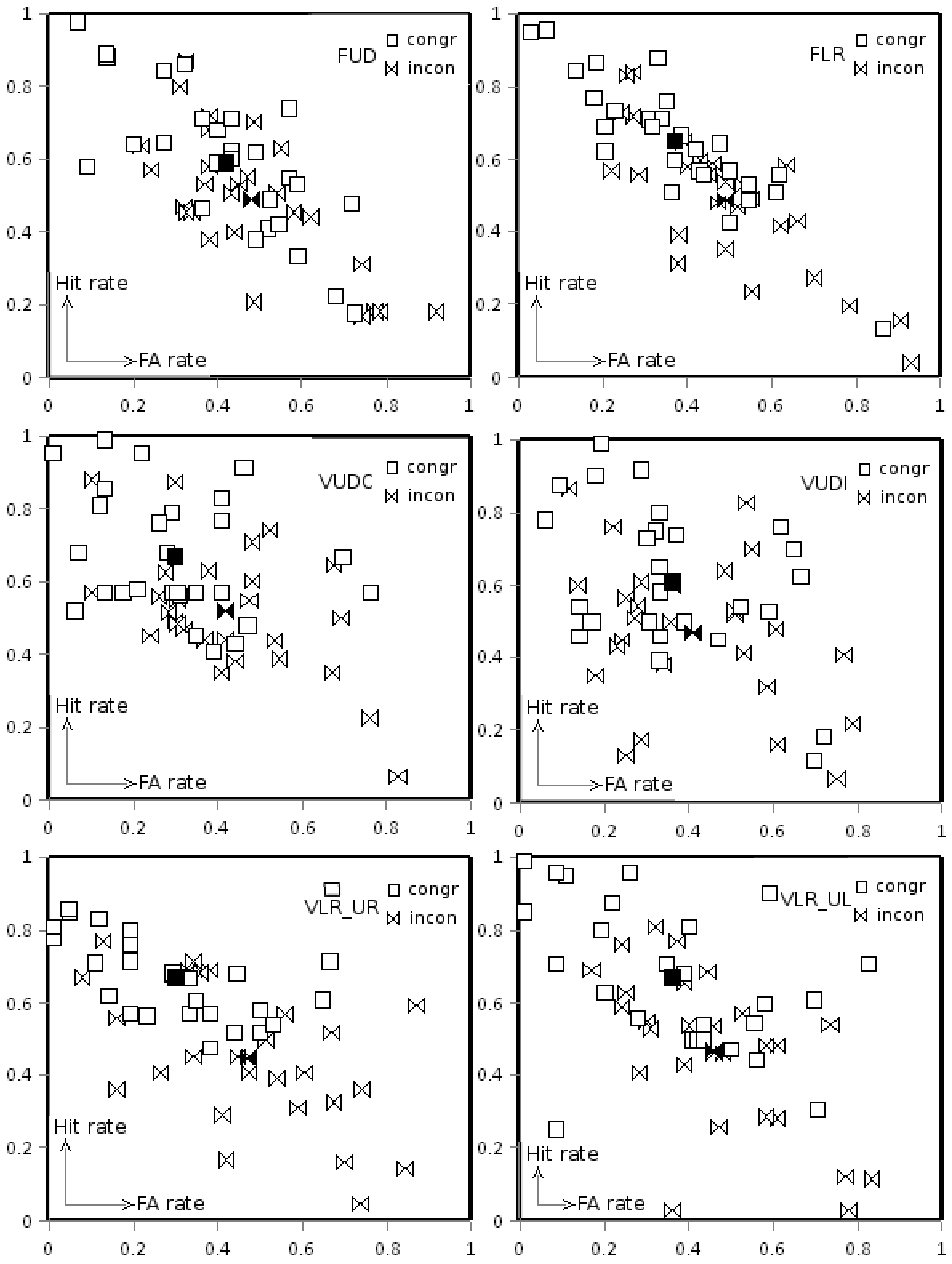


Figure 4: Individual (white symbols) and average (black symbols) hit rates on the y axis plotted as a function of individual and average false alarm (FA) rates on the x axis as a function of the six mapping conditions and the level of congruence (congruent = square symbols; incongruent = spool-shaped symbols) in Experiment 1a. Low prime discrimination can be inferred from average equal hit and FA rates. It can be seen that prime discrimination was better than chance in congruent but not in incongruent conditions in all of the mapping

conditions. (F = fixed mapping; V = variable mapping; UD = up vs. down responses; LR = left vs. right responses; C = compatible; I = incompatible; congr = congruent; incon = incongruent; UR = up primes required right responses [and down primes left responses]; UL = up primes required left responses [and down primes right responses]). Note that performance in the fixed mapping conditions was collapsed across (orthogonally) compatible and incompatible conditions, because in the fixed mapping conditions compatibility was realized as a between-participants variable and without effect.

These tests showed whether or not participants saw the primes in the most straightforward manner. As can be seen in Table 3 the t tests confirmed the impression one gets from looking at Figure 1: d' was significantly greater than 0 in all of the congruent conditions except fixed up/down congruent condition, and it was not significantly different from 0 in any of the incongruent conditions.

In addition, three ANOVAs were conducted to assess *d'* as a function of the independent variables. In the ANOVAs, significance was inferred from an alpha level below .05, and all follow-up tests were Bonferroni corrected here and throughout the study. Because the design was not fully factorial in Experiment 1a, a first ANOVA was conducted with data collapsed across compatible and incompatible conditions. This ANOVA concerned the two within-participants variables mapping (fixed vs. variable) and congruence (congruent vs. incongruent prime-target sequence). This ANOVA led to a significant main effect of congruence, $F(1, 26) = 8.29$, $p < .01$, partial $\eta^2 = 0.24$, with better performance in the congruent condition ($M = 0.83$) than in the incongruent condition ($M = 0.03$). It also led to a significant main effect of mapping, $F(1, 26) = 4.27$, $p < .05$, partial $\eta^2 = 0.14$, with better performance in the variable ($M = 0.53$) than in the fixed mapping condition ($M = 0.33$). Additional *t* tests against zero showed that in the congruent condition *d'* (averaged across all other variables) was different from zero, $t(26) = 4.74$, $p < .001$, but that this was not the case in the incongruent condition, $t < 1.00$, and that average *d'* was different from zero in both fixed mapping and variable mapping conditions, both *t*s(26) > 3.00, both *p*s < .01. (In the ANOVA, the two-way interaction of Mapping and Congruence was not reliable, $F < 1$.)

To assess also the influence of spatial compatibility by an ANOVA, a second ANOVA concerning only the conditions with up and down responses was conducted. This ANOVA was run on fixed up/down (FUD) conditions and the associated partial data from the variable-up/down (VUD) mapping conditions: To transform the variable prime-response compatibility into a pure between-participants variable, for all those of our participants who had a compatible mapping in the fixed block, only the performance in the compatible conditions of the variable-up/down mapping blocks was considered for this analysis, and for all those of our participants who had an incompatible mapping in the fixed block, only the performance in the incompatible conditions of the variable-up/down mapping blocks was considered. The ANOVA, with the between-participants variable compatibility (compatible vs. incompatible) and the within-participant variable congruence (congruent vs. incongruent) was conducted with data collapsed across the levels of the variable, mapping. This ANOVA also confirmed a significant main effect of congruence, $F(1, 26) = 5.07$, $p < .05$, partial $\eta^2 = 0.17$, with better performance in the congruent ($M = 0.67$) than in the incongruent ($M = 0.09$) condition. However, there was neither a significant main effect of compatibility nor a significant interaction between the variables, both *F*s < 1.00, both *p*s > .05. Additionally, *t* tests against zero again showed a significant average *d'* in the congruent condition, $t(26) = 3.47$, $p < .01$, but not in the incongruent condition, $t < 1.00$, *ps* > .05.

A third ANOVA assessed *d'* in the conditions with left and right responses as a function of congruence (congruent vs. incongruent) and mapping (fixed vs. variable). Again, a significant main effect of congruence, $F(1, 26) = 8.85$, $p < .01$, partial $\eta^2 = 0.25$, was found, with better performance in the congruent condition ($M = 0.92$) than in the incongruent condition ($M = -0.05$). Additionally, *t* tests against zero showed a significant difference from zero in the congruent condition, $t(26) = 4.95$, $p < .01$, but not in the incongruent condition, $t < 1.00$. No other significant effect was observed, i.e., all *Fs* < 1, and *ps* > .05.

Biases in Experiment 1a. We also calculated the participants' individual biases (log β; cf. Wickens, 2001). The same three ANOVAs as for *d'* were also conducted for log β. But the results did not reveal any significant effect or interaction in either of the ANOVA, all *F*s < 1, and all *p*s > .05.

Results of Experiment 1b. To bolster the conclusions, we also conducted an ANOVA on *d'* values, with the within-participant variables congruence (congruent vs. incongruent), compatibility (prime-response compatible vs. incompatible), mapping (fixed vs. varied prime-response mapping), and axis (vertical vs. horizontal response axis). Once again, the ANOVA confirmed the existence of a significant congruence effect, $F(1, 9) = 8.05$, $p < .05$, with better performance in congruent (M = 1.24, *d'* range: 0.57 – 1.75) than incongruent (M = 0.48, *d'* range: 0.11 – 0.67) conditions. Additionally *t* tests against zero revealed that participants performed better than chance in the congruent condition, $t(9) = 6.37$, $p < 0.01$, and almost better than chance in the incongruent condition, $t(9) = 2.11$, $p = .06$. No other significant effect nor interaction was found, all *p*s > 0.05.

Table 3. *T* test results of tests of mean *d'* against zero visibility (*d'* = 0) for different conditions of Experiment 1a. The degrees of freedom in all tests were 26. (Sig. = significance [2-tailed]; CI = confidence interval [lower bound – upper bound]; F = fixed mapping; V = variable mapping; UD = up vs. down responses; LR = left vs. right responses; C = compatible; I = incompatible; congr = congruent; incon = incongruent; UR = up primes required right responses [and down primes left responses]; UL = up primes required left responses [and down primes right responses]. Significance was assumed if $p \leq .05$. Fat print = significant.) Correcting the alpha-level for family-wise error, the level of significance was achieved with .05/12 = .004. As can be seen, all congruent *d'* values but the one in condition FUD_congr passed this level.

Tests	***t***	**Sig.**	**Mean *d'***	**95% CI of *d'***
FUD_congr	2.49	**.020**	.53	.09 – .97
FUD_incon	-.05	.958	-.01	-.4 – .38
FLR_congr	3.79	**.001**	.83	.38 – 1.28
FLR_incon	-.23	.820	-.05	-.49 – .39
VUDC_congr	5.34	**.000**	1.13	.69 – 1.57
VUDC_incon	1.13	.271	.19	-.16 – .55
VUDI_congr	3.8	**.001**	.78	.36 – 1.21
VUDI_incon	1.13	.270	.22	-.18 – .63
VLR_UR_congr	6.19	**.000**	1.05	.7 – 1.41
VLR_UR_incon	-.3	.764	-.06	-.49 – .37
VLR_UL_congr	3.98	**.000**	.95	.46 – 1.45
VLR_UL_incon	-.14	.892	-.03	-.46 – .4

Discussion

The results of Experiment 1 showed that only one sort of confusion, namely that incurred by prime-target similarity consistently affected performance. As we had expected, prime discrimination was better in congruent than incongruent conditions, with the exception of the fixed up-down response mapping block in Experiment 1a (see Table 3). This effect makes clear that one source of confusion could be the similarity of prime and target – that is, the confusion of prime identity and target (dummy) identity, so that prime discrimination performance appeared to be lower in incongruent conditions, in which target identity would have suggested an alternative judgment. Alternatively the same deteriorating effect of incongruence on the precision of judgments about the prime's identity could have also been a consequence of a bias to judge with the target dummy word's identity when two conditions are fulfilled: a low prime visibility and a close fit of the target to the judgment categories (cf. Vorberg et al., 2004).

There was no significant difference between compatible and incompatible conditions, and only a slight and inconsistent difference between fixed and variable mapping conditions in the first ANOVA of Experiment 1a but not in the third ANOVA (of the judgments via the left and right responses) and also not in Experiment 1b. This is interesting. It suggests that awareness-independent response activation by the masked primes was not the factor responsible for the congruence effect in the variable mapping conditions: Otherwise, on the basis of direct parameter specification we would have expected that awareness-independent response activation should have affected performance differences between congruent and incongruent conditions in only the fixed but not the variable mapping conditions. Only in the fixed mapping conditions, participants knew the prime-response mapping in advance. Related, we noted that whether a compatible or an incompatible response was used did not matter much for prime discrimination. Therefore, the confusion between the prime's short-term response meaning and its long-term meaning was also without effect.

A final aspect concerns the overall better performance in Experiment 1b than 1a. Although the basic pattern was replicated with better performance in congruent than incongruent conditions, performance in the incongruent conditions was also better than chance. We do not exactly know what factor was responsible for the better discrimination in Experiment 1b than 1a but one possible origin of the performance difference is the greater amount of practice with six blocks in Experiment 1b than 1a.

Experiment 2

In Experiment 1, we observed a prime-target congruence effect in a direct measure task: 'Sensitivity' of the direct measure for the prime words was higher in congruent than in incongruent conditions. If it is true that prime-target confusion or a bias towards target identity judgments is responsible for the performance differences between congruent and incongruent conditions, we should find better performance for the incongruent condition if the set of target (dummy) words does not overlap with the set of prime words.

In order to test this, we used the German words 'weiss' (meaning 'white') and 'schwarz' (meaning 'black') as targets and kept the primes. Under these conditions, the target dummy words are no longer as easily confusable with the prime words because the target dummy words do not fit to the task of discriminating between spatial prime word meanings. Related, under these conditions, a bias to judge with the target dummy word's identity is ruled out because the target word's identity does not fit to the required judgment categories.

One consequence of our manipulation is that the variable 'congruence' would be lost for the analysis. However, for the purpose of our analysis, data were sorted by a factor roughly mimicking 'congruence' levels on the basis of a closer association between white and up, and black and down than between white and down, and black and up (cf. Meier & Robinson, 2004).

Method

Participants. Eighteen students (10 female) with a mean age of 24 years participated.
Apparatus, stimuli, and procedure were similar to Experiment 1a, except that the target dummy words were the spatially neutral German words ‘weiss’ and ‘schwarz’. We modeled congruent conditions as up-white and down-black prime-target relations, and incongruent conditions as down-white and up-black prime-target relations.

Results

Data of two participants were discarded due to extremely consistent performance (e.g., more than 95% of either ‘up’ or ‘down’ judgments). Because participants were informed about the equal probabilities of up and down primes, these participants evidently failed to understand the prime visibility task. Individual hit and FA rates are shown in Figure 5. It can be seen that d’ is not or only slightly affected by whether prime-target relations were ‘congruent’ or ‘incongruent’. In line with this, there were no major differences of sensitivity between congruent and incongruent, that is, d’ was different from zero in all of the tests. See Table 4.

Additional analyses and biases. The same three ANOVAs as in Experiment 1a were also performed here for the visibility indices (*d’*) and biases (log β). Neither the *d’* nor the log β analysis led to any significant effect or interaction, all *F*s < 1.00, and all *p*s > .05.

Comparison between Experiments 1a and 2. We also compared the performance in Experiments 1a and 2 by first collapsing the data across levels of the variable compatibility and taking experiment as an additional between-participants variable. This ANOVA of *d’* with the variables mapping, congruence, and experiment led to a significant main effect of experiment with *d’* in Experiment 1a ($M = 0.43$) being significantly smaller than in Experiment 2 ($M = 1.17$), $F(1, 41) = 14.38$, $p < .01$, partial $\eta^2 = 0.26$. Also the two-way interaction of congruence and experiment was significant, $F(1, 41) = 6.00$, $p < .05$, partial $\eta^2 = 0.13$. Subsequent pairwise *t* tests of congruent conditions between experiments and of incongruent conditions between experiments showed that the *d’*s were significantly smaller in Experiment 1a’s incongruent condition ($M = 0.03$) than in Experiment 2’s incongruent condition ($M = 1.27$), $t(41) = 4.52$, $p < .01$, but differences were not significant between the congruent conditions of Experiment 1a ($M = 0.83$) and Experiment 2 ($M = 1.07$), $t < 1.00$.

A second ANOVA of the data was restricted to the judgments that were given via the up and down responses. This ANOVA was selectively run with that part of the data from the blocks with a variable prime-response mapping of each participant in which the same prime-response mapping was used as in the respective participant’s fixed mapping block. Corroborating the conclusions from the first ANOVA, this ANOVA with the within-participant variable congruence, and the between-participants variables compatibility and experiment again showed a significant main effect of experiment with lower performance in Experiment 1a ($M = 0.39$) than in Experiment 2 ($M = 1.05$), $F(1, 41) = 9.19$, $p < .01$, partial $\eta^2 = 0.19$, and a significant two-way interaction of congruence and experiment, $F(1, 41) = 4.12$, $p < .05$, partial $\eta^2 = 0.10$. Follow-up pairwise *t* tests showed that *d’*s were significantly smaller in Experiment 1a’s incongruent condition ($M = 0.09$) than in Experiment 2’s incongruent condition ($M = 1.15$), $t(41) = 4.00$, $p < .01$, but again differences were not significant between the congruent conditions of Experiment 1a ($M = 0.67$) and Experiment 2 ($M = 0.95$), $t < 1.00$.

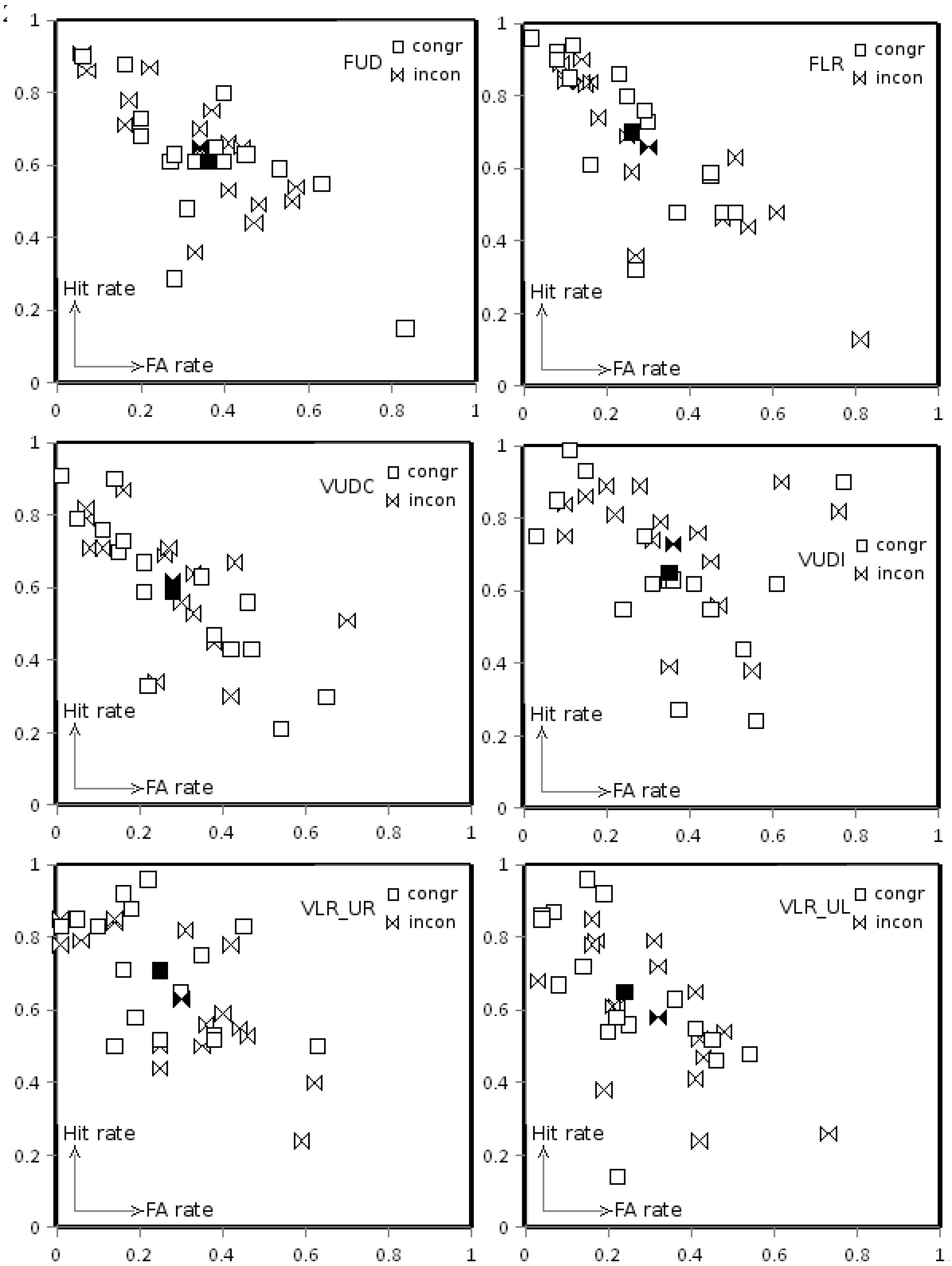


Figure 5: Individual (white symbols) and average (black symbols) hit rates on the y axis plotted as a function of individual and average false alarm (FA) rates on the x axis as a function of the six mapping conditions and congruence ('congruent' = 'up' prime before 'white' target/ 'down' prime before 'black' target = square symbols; incongruent = 'up' prime before 'black' target/ 'down' prime before 'white' target = spool-shaped symbols) in Experiment 2. Equal prime discrimination in the congruent and incongruent conditions can be inferred from average equal hit and FA rates. (F = fixed mapping; V = variable mapping; UD = up vs. down responses; LR = left vs. right responses; C = compatible; I = incompatible; congr = 'congruent'; incon = 'incongruent'; UR = up primes required right responses [and down primes left responses]; UL = up primes required left responses [and down primes right responses]). Note that performance in the fixed mapping

conditions was collapsed across (orthogonally) compatible and incompatible conditions, because in the fixed mapping conditions compatibility was realized as a between-participants variable and without effect.

A third ANOVA was restricted to only the judgments that were given by left and right button presses. For this ANOVA data were collapsed across the non-significant level of orthogonal compatibility. This ANOVA, with the within-participant variables mapping and congruence, and the between-participants variable experiment also showed a significant main effect of experiment, with lower performance in Experiment 1a (*M* = 0.44) than in Experiment 2 (*M* = 1.29), $F(1, 41) = 17.66$, $p < .01$, partial $\eta^2 = 0.30$, and a significant two-way interaction of congruence and experiment, $F(1, 41) = 5.87$, $p < .05$, partial $\eta^2 = 0.13$. Subsequent pairwise *t* tests of congruent and incongruent conditions between experiments again showed that average *d* was significantly smaller in Experiment 1a's incongruent condition (*M* = -0.05) as compared to Experiment 2's incongruent condition (*M* = 1.34), $t(41) = 4.60$, $p < .01$, but that the differences were not significant between the congruent conditions of Experiment 1a (*M* = 0.92) and Experiment 2 (*M* = 1.20), $t < 1.00$. No other main effect or interaction was significant in this ANOVA, all *F*s < 1.00.
The same ANOVA between experiments for Log β also did not show any significant effect or interaction, all *F*s < 1.00, and all *p*s > .05.

Table 4. *T* test results of tests of mean *d'* against zero visibility (*d'* = 0) for different conditions of Experiment 2. The degrees of freedom in all tests were 15. (Sig. = significance [2-tailed]; CI = confidence interval [lower bound – upper bound]; F = fixed mapping; V = variable mapping; UD = up vs. down responses; LR = left vs. right responses; C = compatible; I = incompatible; congr = congruent ['up' primes preceded by 'white' target and 'down' by 'black']; incon = incongruent ['up' primes preceded by 'black' target and 'down' by 'white']; UR = up primes required right responses [and down primes left responses]; UL = up primes required left responses [and down primes right responses]. Significance was assumed if $p \leq .05$. Fat print = significant.) Correcting the alpha-level for family-wise error, the level of significance was achieved with .05/12 = .004. As can be seen, all congruent and incongruent *d'* values passed this level.

Tests	***t***	**Sig.**	**Mean *d'***	**95% CI of *d'***
FUD_congr	3.72	**.002**	.97	.41 – 1.52
FUD_incon	4.23	**.001**	1.08	.53 – 1.62
FLR_congr	4.15	**.001**	1.17	.57 – 1.77
FLR_incon	5.44	**.000**	1.57	.96 – 2.19
VUDC_congr	3.57	**.003**	.88	.36 – 1.41
VUDC_incon	5.56	**.000**	1.32	.82 – 1 .83
VUDI_congr	3.56	**.003**	.93	.37 – 1.48
VUDI_incon	5.09	**.000**	1.17	.68 – 1.66
VLR_UR_congr	4.49	**.000**	1.3	.68 – 1.91
VLR_UR_incon	4.55	**.000**	1.25	.66 – 1.83
VLR_UL_congr	4.02	**.001**	1.16	.54 – 1.78
VLR_UL_incon	5.25	**.000**	1.16	.69 – 1.63

Discussion

Experiment 2 indicated that with a low similarity between prime and target dummy word the performance difference between different types of prime-target relations, that is, between 'congruent' and 'incongruent' conditions, is overcome. In addition, performance in Experiment 2 was better than in Experiment 1a and there was again not the slightest indication that performance in incompatible conditions differed from that in compatible conditions. Taken together, the results suggest that a high prime-target similarity in Experiment 1 created a number of wrongly judged prime identities in incongruent conditions.

General Discussion

Research in the area of masked priming has claimed that even if the participants remain unaware of the masked primes, primes affect the processing of subsequent target stimuli and the responses to the targets (see Marcel, 1983). To establish this dissociation, in a masked priming study two separate measures, one direct measure of prime visibility, and one indirect measure of priming need to be collected. It then has to be shown that the effect of the prime in the direct measure – that is, its visibility, is lower than its effect in the indirect measure. Arguably, the conclusion that masked priming reflects subliminal processing of stimuli that remain below the level of awareness is only justified if the even more stringent criterion of zero prime visibility is also met. However, the dissociation procedure might also be used if it is clear that the direct measure is as sensitive for the masked prime or one of its particular features as the indirect measure. Likewise, zero visibility can only be concluded from chance level performance in the direct measure if the direct measure is exhaustive for conscious information about the prime or the priming feature.

Yet, past studies' visibility test procedures or direct measure tasks varied and we therefore conducted two experiments in order to test whether sources of confusion in some of the procedures can affect direct measure performance. Our results confirmed that prime-target congruence affected prime discrimination performance. Prime reports were better in Experiment 1's congruent than incongruent conditions. This effect reflected that an occasional confusion between prime words and target words leads to erroneous judgments of prime identity if the targets suggested using another judgment category than the prime. Alternatively, under these conditions of a low prime visibility and a good fit between judgment categories and target identities, the participants' bias to preferentially judge with the target identity could lead to a lower prime discrimination performance in incongruent than congruent conditions, that is, a less than optimally sensitive direct measure. Our findings are also in line with results of a study of Greenwald et al. (2003). In that study, prime identities had to be reported under conditions in which either a congruent target or an incongruent target followed the prime. Under these conditions, the average accuracy of the prime report was much lower than in a task in which the prime's presence had to be detected under otherwise identical conditions.

It is very likely that this effect reflected a true decrement of the sensitivity of the visibility measure in the incongruent conditions and not an undue awareness-independent performance-boosting response activation effect in the congruent conditions of Experiment 1. Two arguments support this conclusion. First, if primes affected Experiment 1's prime visibility measures by an awareness-independent response-activation effect, we would have expected better overall performance in the fixed mapping conditions than in the variable mapping conditions: Only in the fixed mapping conditions, awareness-independent direct parameter specification by the prime could have unduly improved performance. Yet, there was no overall better performance in the fixed than in the variable mappings. Second, one might argue that the better performance in the congruent condition of Experiment 1 was not due to a higher sensitivity of the direct measure for the prime's visibility in the congruent than in the incongruent condition but in fact reflected automatic and awareness-independent response activation by the prime's long-term meaning that falsely suggested a better prime visibility (cf. Ansorge et al., 2010). On the basis of this explanation, however, one would have expected compatibility effects in Experiments 1 and 2, but these were not observed. Thus, it is likely that incorrect judgments based on the identity of the visible targets in Experiment 1's incongruent conditions were especially harmful for the sensitivity of the direct measure. In conclusion, it is much more likely that the overall better performance in Experiment 2 reflected the prime's true visibility.

Taken together our data suggest that once the visible targets suggest an incorrect response this also increases the chance of a wrong report of target identities instead of the report of the identity of the masked primes. Because performance in Experiment 1a's incongruent conditions was not better than chance, this source of confusion (or this bias to judge with the target's identity) can falsely indicate even chance performance. In Experiment 2 where this source of confusion was abolished, performance was by and large much better than in Experiment 1. Thus, our results suggest that future studies should be careful to avoid that prime-target confusions can decrease the sensitivity of the direct measure. Several steps can be taken to overcome the problems that we have identified here. First, it seems better practice to sometimes leave out the targets in the visibility tests of the masked primes because this would lead to the more conservative test of prime visibility (cf. Dell'Acqua & Grainger, 1999; Eimer & Schlaghecken, 1998, 2002; Schlaghecken, Blagrove, & Maylor, 2007). This has the drawback of a lower similarity between direct and indirect measure task but we should keep in mind that the use of similar measures in direct and indirect measure task is not a goal in itself but instead serves to ensure that the direct measure task that is as sensitive for the priming information as the indirect measure task. Of course, another option is to use prime and target sets with lower overall resemblance between prime and target in the first place (e.g., Kouider & Dupoux, 2004; Marcel, 1983; Merikle & Joordens, 1997). Using this option has the disadvantage that it is not possible to study response priming via direct parameter specification (cf. Kunde, Kiesel, & Hoffmann, 2003). However, using a set of primes and targets of low resemblance might be a viable option if one wants to study semantic priming because the demonstration of semantic priming does not require the use of the same words as primes and targets (cf. Kiefer, 2002). Second, it might also be sometimes advisable to use tasks that are less affected by the visible target words, like present-absent judgments about the masked primes (cf. Ansorge et al., 2010; Dehaene et al., 1998), but presence/absence tasks could also lead to a mismatch between the direct and indirect measures (cf., Schmidt & Vorberg, 2006). If the priming effect is due to some feature of the primes, such as its shape or color that can also be seen when the prime is judged to be absent a low performance in a present/absent task would be misleading with respect to the visibility of the crucial feature responsible for the priming effect. Finally, one can also split up visibility measures for congruent vs. incongruent conditions to test for sensitivity differences between the two conditions (cf. Ansorge et al., 2007; Ansorge et al., 2010). If such an analysis leads to an equally low prime-discrimination performance in congruent and incongruent conditions, one can rule out that a lower prime-discrimination performance in incongruent conditions that was brought about by prime-target confusion or a bias to judge with the target's identity could have falsely suggested an average low prime visibility. If, however, one finds lower prime discrimination performance in incongruent than congruent conditions, a conservative measure of prime-discrimination performance should then be based on the performance in the congruent conditions of the direct measure task only.

A final note concerns the use of fixed vs. variable prime-response mappings: This manipulation was mostly without effect on prime visibility measures. Maybe, it is not necessary to use variable mappings in prime discrimination tasks (cf. Klotz & Neumann, 1999) but definitely the use of variable prime-response mappings has also no detrimental effect on the direct measure task's sensitivity.

References

Abrams, R. L., & Greenwald, A. G. (2000). Parts outweigh the whole word in unconscious analysis of meaning. *Psychological Science*, *11*, 118-124.

Abrams, R. L., Klinger, M. R., & Greenwald, A. G. (2002). Subliminal words activate semantic categories (not automated motor responses). *Psychonomic Bulletin and Review*, *9*, 100-106.

Albrecht, T., Klapötke, S., & Mattler, U. (2010). Individual differences in metacontrast masking are enhanced by perceptual learning. *Consciousness and Cognition*, *19*, 656-666.

Ansorge U., Becker S. I., & Breitmeyer B. G. (2009). Revisiting the metacontrast dissociation: Comparing sensitivity across different measures and tasks. *Quarterly Journal of Experimental Psychology*, *62*, 286-309.

Ansorge, U., Breitmeyer, B. G., & Becker, S. I. (2007). Comparing sensitivity across different processing measures under metacontrast masking conditions. *Vision Research*, *47*, 3335-3349.

Ansorge, U., Horstmann, G., & Worschech, F. (2010). Attentional capture by masked color singletons. *Vision Research*, *50*, 2015-2027.

Ansorge, U., & Neumann, O. (2005). Intentions determine the effect of invisible metacontrast-masked primes: Evidence for top-down contingencies in a peripheral cueing task. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 762-777.

Breitmeyer, B. G., Ro., T., Ogmen, H., & Todd, S. (2007). Unconscious, stimulus-dependent priming and conscious, percept-dependent priming with subliminal stimuli. *Perception & Psychophysics*, *69*, 550-557.

Chen, Z., & Treisman, A. (2009). Implicit perception and level of processing in object substitution masking. *Psychological Science*, *20*, 560-567.

Cho, Y. S., & Proctor, R. W. (2003). Stimulus and response representations underlying orthogonal stimulus-response compatibility effects. *Psychonomic Bulletin & Review*, *10*, 45–73.

Cressman, E. K., Franks, I. M., Enns, J. T., & Chua, R. (2006). On-line control of pointing is modified by unseen shapes. *Consciousness and Cognition*, *16*, 265-275.

Damian, M. F. (2001). Congruity effects evoked by subliminally presented primes: Automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 154-165.

de Gardelle, V., & Kouider, S. (2010). How spatial frequencies and visual awareness interact during face processing. *Psychological Science*, *21*, 58-66.

Dehaene, S., Jobert A., Naccache, L., Ciuciu, P., Poline, J.-B., Le Bihan, D., & Cohen, L. (2004). Letter binding and invariant recognition of masked words: behavioral and neuroimaging evidence. *Psychological Science*, *15*, 307-313.

Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P., & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature*, *395*, 597-600.

De Jong, R., Liang, C.-C., & Lauber, E., (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus-response correspondence. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 731-750.

Dell'Acqua, R., & Grainger, J. (1999). Unconscious semantic priming from pictures. *Cognition*, *73*, 1-15.

DeLong, E. R., DeLong, D. M., & Clarke-Pearson, D. L. (1988). Comparing the areas under two or more correlated Receiver Operating Characteristics curves: A nonparametric approach. *Biometrics*, *44*, 837-845.

Draine, S. G., & Greenwald, A. G. (1998). Replicable unconscious semanti priming. *Journal of Experimental Psychology: General*, *127*, 286-303.

Duncan, J., & Humphreys, G.W. (1989). Visual search and visual similarity. *Psychological Review*, *96*, 433–58.

Eimer, M., & Schlaghecken, F. (1998). Effects of masked stimuli on motor activation: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1737-1747.

Eimer, M., & Schlaghecken, F. (2002). Links between conscious awareness and response inhibition: Evidence from masked priming. *Psychonomic Bulletin & Review, 9*, 514-520.

Eriksen C.W. (1960). Discrimination and learning without awareness: a methodological survey and evaluation. *Psychological Review*, *67,* 279–300.

Finkbeiner, M., & Palermo, R. (2009). The role of spatial attention in nonconscious processing: A comparison of face and non-face stimuli. *Psychological Science, 20*, 42-51.

Fitts, P. M., & Seeger, C. M. (1953). SR compatibility: spatial characteristics of stimulus and response codes. *Journal of Experimental Psychology*, *46*, 199-210.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.

Greenwald, A. G., Abrams, R. L., Naccache, L., & Dehaene, S. (2003). Long-term semantic memory versus contextual memory in unconscious number priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 235-247.

Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science*, *273*, 1699-1702.

Hirshman, E., & Durante, R. (1992). Prime identification and semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 255-265.

Holender D. (1986) Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: a survey and appraisal. *Behavorial and Brain Sciences*, 9, 1–23.

Jacoby, L. L., Toth, J. P., & Yonelinas, A. P. (1993). Separating conscious and unconscious influences of memory: Measuring recollection. *Journal of Experimental Psychology: General*, *122,* 139–154.

Jaśkowski, P., Skalska, B., & Verleger, R. (2003). How the self controls its 'automatic pilot' when processing of subliminal information. *Journal of Cognitive Neuroscience, 15,* 911-920.

Jaśkowski, P., van der Lubbe, R. H. J., Schlotterbeck, E., & Verleger, R. (2002). Traces left on visual selective attention by stimuli that are not consciously identified. *Psychological science*, *13*, 48-54.

Kiefer, M. (2002). The N400 is modulated by unconsciously perceived masked words: Further evidence for a spreading activation account of N400 priming effects. *Cognitive Brain Research*, *13*, 27-39.

Kiefer, M., & Brendel, D. (2006). Attentional modulation of unconscious 'automatic' processes: Evidence from event-related potentials in a masked priming paradigm. *Journal of Cognitive Neuroscience*, *18*, 184-198.

Kiesel, A., Kunde, W., Pohl, C., Berner, M.P., & Hoffmann, J. (2009). Playing chess unconsciously. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*, 292-298.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, *15*, 20-25.

Kiesel, A., Wagener, A., Kunde, W., Hoffmann, J., Fallgatter, A. J., & Stöcker, C. (2006). Unconscious manipulation of free choice in humans. *Consciousness and Cognition, 15*, 397-408.

Klotz, W., & Neumann, O. (1999). Motor activation without conscious discrimination in metacontrast masking. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 976-992.

Klotz, W., & Wolff, P. (1995). The effect of a masked stimulus on the response to the masking stimulus. *Psychological Research/Psychologische Forschung*, *58,* 92-101.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility - A model and taxonomy. *Psychological Review*, *97*, 253-270.

Kouider, S., & Dupoux, E. (2004). Partial awareness creates the 'illusion' of subliminal semantic priming. *Psychological Science*, *15*, 75-81.

Kunde, W. (2003). Sequential modulations of stimulus-response correspondence effects depend on awareness of response conflict. *Psychonomic Bulletin & Review, 10*, 198-205.

Kunde, W., Kiesel, A., & Hoffmann, J. (2003). Conscious control over the content of unconscious cognition. *Cognition*, *88*, 223-242.

Lau, H.C., & Passingham, R. E. (2007). Unconscious activation of the cognitive control system in the human prefrontal cortex. *Journal of Neuroscience*, *27*, 5805-5811.

Leuthold, H., & Kopp, B. (1998). Mechanisms of priming by masked stimuli: Inferences from event-related potentials. *Psychological Science, 9*, 263-269.

Lu, C. H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review, 2,* 174-207.

Marcel, A. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology*, *15*, 197-237.

Mattler, U. (2003). Priming of mental operations by masked stimuli. *Perception & Psychophysics*, *65*, 167-187.

Mattler, U. (2006). On the locus of priming and inverse priming effects. *Perception & Psychophysics*, *68*, 975-991.

Mattler, U. (2007). Inverse target- and cue-priming effects of masked stimuli. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 83-102.

Meier, B. P., & Robinson, M.D. (2004). Why the sunny side is up. Associations between affect and vertical position. *Psychological Science, 15*, 243-247.

Merikle, P.M., & Joordens, S. (1997). Parallels between perception without attention and perception without awareness. *Consciousness and Cognition, 6*, 219–236.

Naccache, L., & Dehaene, S. (2001). Unconscious semantic priming extends to novel unseen stimuli. *Cognition*, *80*, 215-229.

Naccache, L., Blandin, E., & Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science*, 416-424.

Neumann, O. (1990). Direct parameter specification and the concept of perception. *Psychological Research*, *52*, 207-215.

Neumann, O., & Klotz, W. (1994). Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification? In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 123-150). Cambridge, MA: MIT Press.

Pohl, C., Kiesel. A., Kunde, W., & Hoffmann, J. (2010). Early and late selection in unconscious information processing. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 268-285.

Przekoracka-Krawczyk, A., & Jaśkowski, P. (2007). Perceptual learning can reverse subliminal priming effect. *Perception & Psychophysics*, *69*, 558-566.

Reingold, E. M., & Merikle, P. M. (1988). Using direct and indirect measures to study perception without awareness. *Perception & Psychophysics*, *44*, 563-575.

Schlaghecken, F., Blagrove, E., & Maylor, E. A. (2007). Incidental learning of S-R contingencies in the masked prime task. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 1177-1188.

Schmidt, T. (2002). The finger in flight: Real-time motor control by visually masked color stimuli. *Psychological Science*, *13*, 112-117.

Schmidt, T., Niehaus, S., & Nagel, A. (2006). Primes and targets in rapid chases: Tracing sequential waves of motor activation. *Behavioral Neuroscience, 120,* 1005-1016.

Schmidt, T., & Vorberg, D. (2006). Criteria for unconscious cognition: Three types of dissociation. *Perception & Psychophysics*, *68*, 489-50.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: 1. Detection, search, and attention. *Psychological Review*, *84*, 1-66.

Schubö, A., Schlaghecken, F., & Meinecke, C. (2001). Learning to ignore the mask in texture segmentation tasks. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 919-931.

Tapia, E., Breitmeyer, B. G., & Shooner, C.R. (2010). Role of task-directed attention in nonconscious and conscious response priming by form and color. *Journal of Experimental Psychology: Human Perception and Performance*, *36*, 74-87.

Vath, N., & Schmidt, T. (2007). Tracing sequential waves of rapid visuomotor activation in lateralized readiness potentials. *Neuroscience, 145,* 197-208.

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. *Proceedings of the National Academy of Science*, *100*, 6275–6280.

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2004). Invariant time-course of priming with and without awareness. In C. Kaernbach, E. Schröger & H. Müller (Eds.), Psychophysics Beyond Sensation: Laws and Invariants of Human Cognition (pp. 273-290). Hillsdale, NJ: Lawrence Erlbaum Associates.

Weiskrantz, L., Warrington, E.K., Sanders, M.D., & Marshall, J. (1974). Visual capacity in the hemianopic field following a restricted occipital ablation. *Brain*, *97*, 709-728.

Wickens, T. D. (2001) *Elementary Signal Detection Theory*. New York: Oxford University Press.

Wolford, G., Marchak, F., & Hughes, H. (1988). Practice effects in backward masking. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 101-112.

Zhang, H., Zhang, J., & Kornblum, S. (1999). An interactive activation model of stimulus-stimulus and stimulus-response compatibility. *Cognitive Psychology*, *38*, 386-432.

Footnotes

[1] We are grateful to Chris Oriet for pointing this deficit of our design out to us, and we are indebted to Reinhard Kartusch for help with the data collection.

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Supported by Deutsche Forschungsgemeinschaft Grant An 393/5-1 to Ulrich Ansorge, Werner Klotz and Ingrid Scharlau. Thanks to Chris Oriet, Thomas Schmidt, and one anonymous Reviewer for excellent comments on prior versions of the present article.

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4. Testing the Theory of Embodied Cognition with Subliminal Words

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Journal Publication Citation:

Ansorge, U., Kiefer, M., Khalid, S., Grassl, S., & König, P. (2010). Testing the Theory of Embodied Cognition with Subliminal Words. *Cognition*, 116, 303–320. (DOI:10.1016/j.cognition.2010.05.010)

Abstract

In the current study, we tested the embodied cognition theory (ECT). The ECT postulates mandatory sensorimotor processing of words when accessing their meaning. We test that prediction by investigating whether invisible (i.e., subliminal) spatial words activate responses based on their long-term and short-term meaning. Masking of the words is used to prevent word visibility and intentional elaboration of the words' semantic content. In this way, masking specifically isolates mandatory sensorimotor processing of words as predicted by the ECT. Do spatial subliminal words activate responses nonetheless? In Experiment 1, we demonstrate a spatial congruence effect of the invisible words if they precede visible target words. In Experiment 2, we show that masked words activate responses based on their long-term meaning. In Experiment 3, we demonstrate that masked words are also processed according to their short-term response meaning. We conclude that the ECT is supported by our findings and discuss implications of our results for embodied theories of semantic word processing and masked priming experiments.Testing the Theory of Embodied Cognition with Subliminal Words.

Introduction

According to the embodied cognition theory (ECT), semantic representations are grounded in sensorimotor (including sensory) representations (Barsalou, 1999; Kaschak & Glenberg, 2000; Kiefer & Spitzer, 2001; Niedenthal, 2007; Niedenthal et al., 2005). To understand the core assumptions of the ECT, consider Barsalou's (1999) *perceptual symbol systems theory*, which is one example of an ECT. This theory draws upon the importance of perception and episodic memory for grounding semantic knowledge in sensorimotor representations (Barsalou, 1999). According to that theory, sensorimotor representations are stored as particular instances providing a source for abstract semantic representations. The latter are the common characteristics of several instances of sensorimotor representations. According to ECT, semantic and sensorimotor processes should be governed to some extent by similar principles. As a consequence, the effects of semantically processing a word should at least partly resemble the effects of the sensorimotor processing of perceptual representations that are the foundations of the meaning of the words.

This idea is supported by neuroimaging studies showing that the conceptual processing of word meaning activates sensory and motor systems of the human brain (for an overview, see Martin & Chao, 2001): verification of visual and action-related object attributes is associated with activity in visual and motor areas as a function of the relevance of visual and action-related features defining a given concept (Hoenig et al., 2008). Similarly, recognizing words that denote objects related to sound (e.g., the word 'telephone') activates auditory association areas that are also activated when participants listen to real sounds (Kiefer et al., 2008). In both of these studies, activity in sensory and motor areas emerged very rapidly within the first 200 ms of word processing, suggesting that the activity reflected access to the concepts rather than post-recognition imagery. These findings demonstrate that the appreciation of conceptual word meaning depends on a partial reinstatement of brain activity during perception and action.

Behavioural studies have substantiated the importance of sensory and motor representations for conceptual processing. Sentence comprehension evokes compatible or fitting actions (cf. Glenberg & Kaschak, 2002) and mental images (cf. Richardson & Matlock, 2007; Zwaan, Stanfield, & Yaxley, 2002). Priming studies have shown that action representations facilitate object recognition and naming (Helbig, Graf, & Kiefer, 2006, Helbig, Steinwender, Graf, & Kiefer, 2010). Furthermore, a single word implicitly evokes an action when the meaning of larger linguistic expressions is accessed (Masson, Bub, & Newton-Taylor, 2008).

Importantly for the ECT, long-term and short-term meanings of a word can activate responses. Long-term meaning denotes participants' knowledge of word meaning based on past (pre-experimental) experience with the words and their referents. In contrast, short-term meaning denotes participants' knowledge of word meaning as this is defined in the context of the experiment. Short-term meaning is, for instance, defined by instructions on how to use the words in an experiment: for example, it has long been known that simply assigning alternative particular response meanings to letters or words can increase interference between these letters based on their short-term response meaning (cf. Eriksen & Eriksen, 1974). This kind of arbitrary meaning assignment is of course to be expected for words and letters, because only by definition can most words or letters take on any particular meaning.

Critically for the ECT, however, such response meaning assignment not only has temporary, but also long-lasting impact. The long-term meaning of a word can also activate responses even without an explicit instruction. For example, in responding to the words 'left' and 'right' by pressing the right key for a green word and the left key for a red word, participants are faster with the word 'right' in green than with the word 'right' in red (Proctor & Vu, 2002). These results indicate that the spatial long-term meaning of a word can automatically activate a response. Although the word's spatial long-term meaning is irrelevant for the responses in the specific task, this word meaning activates a response corresponding to its side. In spatially corresponding conditions, this automatic response activation by the word (e.g., left) facilitates selection of the required response (e.g., left) to the word's color whereas in non-corresponding conditions, the automatically activated response (e.g., left) is in conflict with the required response (e.g., right) and interferes with it.

So far, the evidence for the ECT from the processing of the long-term meanings of words is restricted to conditions in which participants were aware of the words or sentences (e.g., Bargh, Chen, & Burrows, 1996; Meier & Robinson, 2004). However, as long as a participant is aware of a word, he or she could intentionally elaborate the word's meaning. Such intentional elaboration of a word by imagery of past perceptions or actions in semantically related episodes could be helpful for illustrating the word's meaning but would not necessarily be an indication that semantic representations of words obligatorily draw upon the grounding sensorimotor representations (Machery, 2007).

Therefore, in the present study, we used subliminal presentation of words: words were shown below the level of the participant's awareness. Subliminal stimuli are used in order to demonstrate obligatory processing according to ECT. This logic has been successfully applied to study emotional facial expressions (Dimberg, Thunberg, & Elmehead, 2000). Here we apply it in studying the abstract long-term meaning of words. With subliminal words, we are in a better position to test whether a word obligatorily triggers sensorimotor processing during the early phases of word processing that lead up to the access to a word's meaning. Note that participants have less chance to intentionally modify their processing of subliminal words (Dixon, 1970; Merikle, Smilek, & Eastwood, 2001). This has been demonstrated by masked word priming. In this experimental procedure, a briefly visually presented word is displayed sandwiched between a preceding and/or a following grapheme string or a row of patterns (Marcel, 1983). Under these conditions, participants see little or nothing of the word. Using a masked word as a prime preceding a subsequent clearly visible target word, one finds a priming effect by the masked word. Its invisibility notwithstanding, a masked word with a meaning congruent to the target word (e.g., the masked prime word 'chair' preceding the visible target word 'table') facilitates the semantic categorization of the target word (or a lexical decision about the target word), in comparison to a masked word with a meaning incongruent to the target word (e.g., the masked prime word 'hair' preceding the visible target word 'table') (cf. Kiefer, 2002).

Important for the rationale of the present study and concerning the decreased chances of intentionally modifying processing in response to such masked words, participants fail to strategically modify the use of the meaning of a subliminal word prime (Forster, 1998). This is demonstrated in conditions in which the meaning of a masked word prime predicts an alternative (or 'opposite') meaning of the subsequent target word. Under these conditions, participants fail to adapt:

they continue to show faster responses in the semantically congruent but less frequently realized conditions than in the more likely incongruent conditions (Cheesman & Merikle, 1985; Greenwald, Abrams, & Draine, 1996). This means that participants' intentional, but non-obligatory imagery of (past) sensorimotor representations in response to a masked word, is much less likely than in response to a clearly visible word.

On the basis of these observations, the demonstration that a masked word's long-term meaning must have a sensorimotor effect would be much more convincing evidence for an obligatory recruitment of sensorimotor representations during the semantic processing of words; that is, it would be more convincing evidence for the ECT compared with visible word presentation, which allows for strategic imagery.

Experiment 1

In Experiment 1, we established a masked word congruence effect reflecting words' spatial meanings. Spatial meaning was chosen for the current study for three reasons. First, it has obvious and well-controllable response affordances as demonstrated in automatic response activation by visible spatial words (Proctor et al., 2000). In addition, the rich and detailed empirical literature on spatial sensorimotor effects of masked stimuli (cf. Ansorge, 2003, 2004; Breitmeyer, Ogmen, & Chen, 2004; Breitmeyer, Ro, & Singhal, 2004; Bridgeman et al., 1979; Eimer & Schlaghecken, 1998; Lleras & Enns, 2004, 2005; Neumann & Klotz, 1994; Leuthold & Kopp, 1998; Schmidt, 2002; Schmidt & Vorberg, 2006) has provided us with an excellent benchmark for what to expect if a word's spatial meaning is grounded on sensorimotor representations. Finally, spatial meaning was chosen because it is a dimension that is highly relevant to various concepts such as affective meaning (Meier & Robinson, 2004), tonal height (Melara & O'Brien, 1987), and numerical meaning (Dehaene, 1992). Spatial elevation, for example, is associated with positive affective meaning, high tonal pitch, and higher numbers.

In Experiment 1, the masked word's spatial meaning was either congruent or incongruent to that of a subsequent visible target word. Presenting the masked prime word 'upward' before the visible target word 'above' is an example of a congruent condition, because both prime word and target word denote an elevated position or a direction towards such a position. Presenting the masked prime word 'down' before the visible target word 'up' is an example of an incongruent condition, because the prime word denotes a downward direction and the target word denotes an elevated position.

We used two tasks: the target response task to test whether masked words influence how efficiently visible words are processed, and the prime visibility task to test whether the masked prime words are presented outside participants' awareness. In the target response task, our participants had to respond with a spatially corresponding response to the visible target word. All prime and target words indicated positions or directions toward positions on the vertical axis (e.g., the words 'above' or 'downward'). Participants had to press an upper key to the target word 'above'. Under these conditions, we expected a congruence effect: lower RTs under congruent conditions (e.g., with the prime word 'below' presented before the target word 'downward') than under incongruent conditions (e.g., with the prime word 'below' presented before the target word 'upward'). This prediction was based on three possible contributions of the prime to the congruence effect (see Figure 1 and Table 1). First, it could be that the masked prime word facilitates the processing of a semantically related target word (cf. Marcel, 1983). This influence will be called semantic priming (SE in Table 1). According to semantic processing theories, semantic priming reflects feature similarity between related primes and targets (McRae & Boisvert, 1998) or reciprocal facilitation between representations in a semantic network or 'mental lexicon' (Collins & Loftus, 1975; Neely, 1977). According to distributed semantic memory models, for example, each word meaning is represented as activation of a number of micronodes representing semantic features (Plaut & Booth, 2000). Once the prime has activated micronodes corresponding to its meaning, subsequent use and activation of the same micronodes involved in the processing of a semantically related target will benefit from the prime’s pre-activation of these micronodes, and the participant’s response to the target will be facilitated.

It is also conceivable that a masked prime word directly influences motor processes as predicted by the ECT. This could be in one of two ways. The prime word could activate a spatial response corresponding to its short-term response meaning. This has been termed “direct parameter specification” in the domain of sensory stimuli (cf. Neumann & Klotz, 1994; Neumann, 1990) and “action triggering” (AT in Table 1) in the domain of words (Kunde, Kiesel, & Hoffmann, 2003). According to the action-trigger hypothesis, an intention to respond to the relevant features of the visible targets is already applied to the target-preceding masked primes. A crucial precondition for this response-activation effect by the masked primes is, therefore, the prime’s similarity to the response-relevant features of the target. This condition is nicely fulfilled in the present experiment, in which the same response-relevant words are used as masked primes and visible targets. By means of action triggering, in the present experiment, the masked prime word would activate the correct response in congruent but not in incongruent conditions.

Finally, it is possible that the masked prime word automatically activates a response based on its long-term spatial meaning. This influence will be called the prime’s automatic response activation (AA in Table 1). This response activation crucially depends on the similarity between the masked prime’s long-term spatial meaning and the spatial meaning of at least one of the responses (cf. De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990). Automatic response activation occurs regardless of visual prime-target similarity. This ECT-compatible response activation effect of a masked prime word is termed ’automatic‘ because it does not crucially hinge on the processing requirements as defined by the task.

In Experiment 1, we estimate the total of these different influences to the masked word’s congruence effect and only discern between different individual contributions thereto in the subsequent Experiments 2 and 3. The main purpose of Experiment 1 is to demonstrate beyond doubt that the masked prime words elicit a congruence effect even when they are not consciously perceived. To that end, three different visibility tests were used (with different participants). All of the variants of the visibility test should demonstrate that the masked prime words were invisible. Visibility task (1) required participants to indicate, in each trial, whether a spatial word or a string of identical capital letters was shown as the masked stimulus. This decision about the word status of the masked stimulus can be considered a very sensitive test of word visibility if the ability to read a word is a crucial prerequisite for understanding its meaning (Marcel, 1983).

It could be the other way around, too—that is, the understanding of a word’s meaning could be a crucial clue for deciding that a stimulus is a word. Therefore, we used visibility tasks (2) and (3), too. Visibility task (2) required participants to judge whether an actual trial was congruent or incongruent. This task might be sensitive not only to the conscious perception of the masked words but also to their unconscious processing. For instance, participants might just use what they felt as their better performance in congruent than incongruent conditions to infer that a masked prime was congruent or incongruent to the visible target word. This makes visibility task (2) less exclusive as a measure of awareness. This drawback was, however, accepted in order to obtain higher sensitivity to any residual visibility of the masked prime word (cf. Reingold & Merikle, 1988). In addition, it can be argued that the congruence judgment is more similar to the target-response task because the former requires participants to wait until the target word is shown before they could give a judgment.

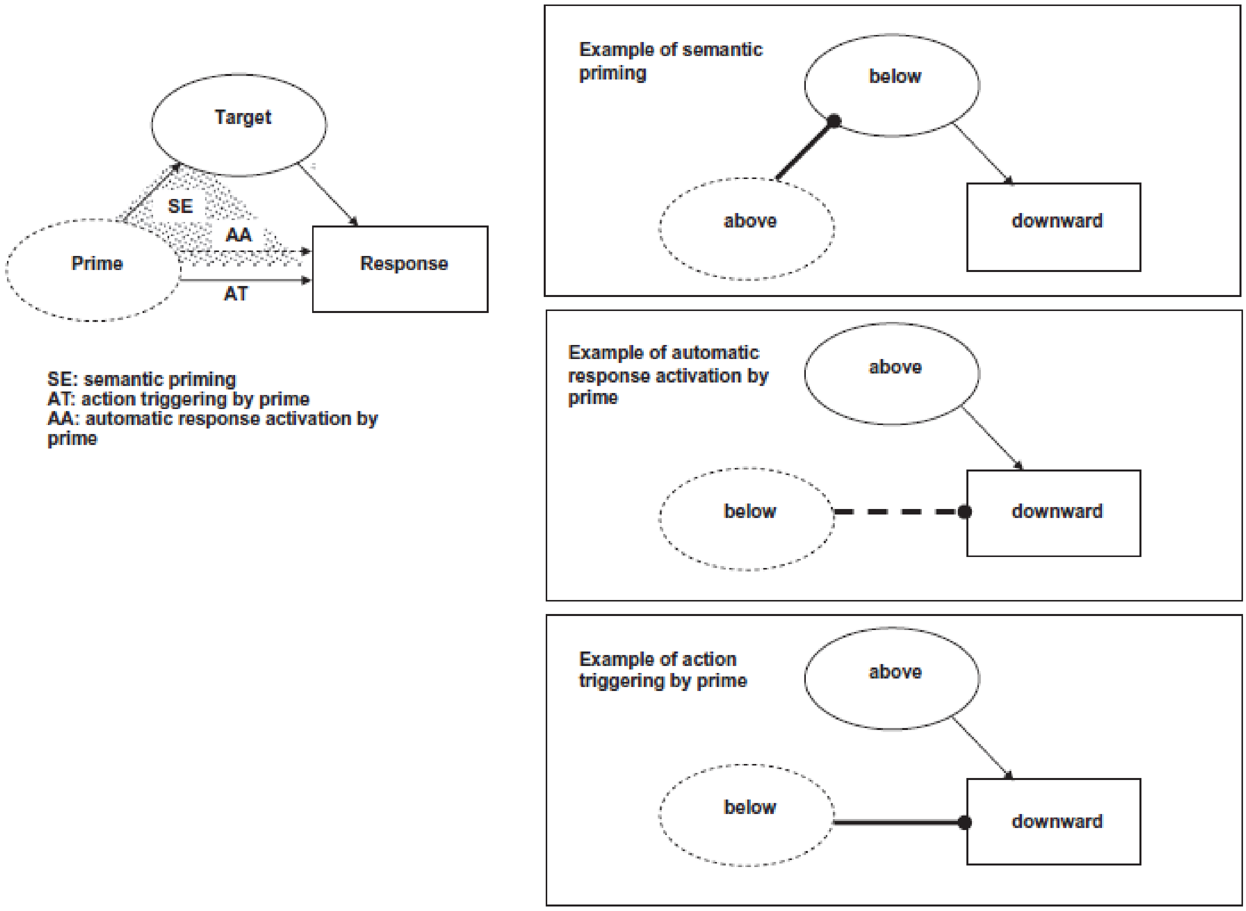

Figure 1: The model of the potential priming effects contributing to the overall congruence effect is depicted on the left. Stimuli (inputs) are depicted as ellipses, either with solid outlines for the supraliminal stimulus (target) or with broken outlines for the subliminal stimulus (prime). Responses (outputs) are depicted as rectangles. Each arrow corresponds to one potential influence of the prime. The arrow connecting prime and target represents semantic priming of targets by primes (abbreviated SE for Semantic priming). The broken arrow connecting prime and response represents the prime's automatic response activation effect (abbreviated as AA). AA effects reflected the prime's long-term meaning. This is indicated by the dotted area. The solid arrow connecting prime and response represents action triggering by the prime according to the instructions – that is, by the response meaning that the stimulus gets via the instructions (abbreviated AT for Action Triggering). AT reflected short-term meaning. This is indicated by AT's position outside the dotted area. On the right, examples of the influences in an incongruent condition are depicted, a semantic priming effect in the top right panel, an automatic response activation in the central right panel, and an action-triggering effect in the lower right panel. (Thick lines with knots at their end indicate inhibition or conflict.)

Visibility task (3) asked participants to discriminate which spatial meaning the masked prime word had. This task is again potentially sensitive to non-conscious processing of the masked prime. For instance, because we required spatially corresponding responses for discriminating between the different masked primes (just as we required spatially corresponding responses for discriminating between the visible words in the behavioral measure), a motor activation by the masked word could automatically increase the number of correct responses. Again, this drawback was accepted for the sake of using a task that is as similar as possible to the target-response task.

Table 1. Overview of the experiments and their important manipulations. Experiment 1 allows three contributions that draw in the same direction and decrease congruent RT relative to incongruent RT (congruence effect). Experiment 2 allows identification of automatic response activation (AA) as one contributing factor to the congruence effect, because only AA should diminish the difference between congruent and incongruent RT relative to Experiment 2 (see opposite sign of the RT difference in row 6 of the table body). In Experiment 3, AA by vertical prime words is altogether prevented by using left vs. right responses. Comparison of Experiments 3a vs. 3b allows identification of action triggering (AT) and 'pure' semantic priming (SE) as contributing factors because only pure SE without concomitant AT should create a congruence effect in Experiment 3a, and because only AT can boost the congruence effect in Experiment 3b as compared to Experiment 3a (compare lines 8 and 10 of the table body).

Exp.	**Prime-*Target* (examples)**		**Response**	**process**	**predicted effect**
	con.	inc.			
1	up-*up*	down-*up*	↑	SE	con. RT < inc. RT
	up-*up*	down-*up*	↑	AT	con. RT < inc. RT
	up-*up*	down-*up*	↑	AA	con. RT < inc. RT
2a	up-*up*	down-*up*	↓	SE	con. RT < inc. RT
	up-*up*	down-*up*	↓	AT	con. RT < inc. RT
	up-*up*	down-*up*	↓	AA	con. RT > inc. RT
3a	up-*6*	down-*6*	→	SE	con. RT < inc. RT
	up-*6*	down-*6*	→	AT	–
	up-*6*	down-*6*	→	AA	–
3b	up-*up*	down-*up*	→	SE	con. RT < inc. RT
	up-*up*	down-*up*	→	AT	con. RT < inc. RT
	up-*up*	down-*up*	→	AA	–

Table note: Concerning Experiment 2a, the same predictions hold in Experiment 2b's non-corresponding conditions. Exp. = experiment; con. = congruent; inc. = incongruent; SE = semantic priming; AT = action triggering; AA = automatic response activation; RT = reaction time; arrows indicate direction of response.

Method

Participants. Sixty-four university students (45 female) with a mean age of 27 years participated in Experiment 1. The participants here and in the other experiments were paid (6 €) or given course credit for participating.

Apparatus. Visual stimuli were presented on a 15-inch, color VGA monitor with a refresh rate of 59.1 Hz. The participants sat at a distance of 57 cm from the screen in a quiet, dimly lit room, with their head resting on a chin rest to ensure a constant viewing distance and a forward gaze direction. Responses and associated RTs (response times) were registered via the numeric keypad of a serial computer keyboard, placed directly in front of the participants. To start a trial, participants pressed the home key #5 with the right index finger. They had to release the home key immediately before their target response. Target responses were given using keys #2 and #8 (labeled 'below' and 'above'). After reading the instructions, participants started the experiment by pressing key #8 once, and continued with the next trial by pressing key #5.

Stimuli and procedure. See Figure 2. Prime and target stimuli were German words denoting spatial positions on the vertical axis. The masked prime and the visible target words could either be ‘oben’ (on top), ‘darüber’ (above), ‘hinauf’’ (upward), ‘hoch’ (high), ‘unten’ (down), ‘darunter’ (below), ‘hinab’ (downward), and ‘tief’ (deep). Each of the eight words was presented as a target and combined with each of the seven remaining words as a prime. Thus, a set of 56 (8 × 7) different prime-target pairs served as stimuli. Prime-target pairs were equally likely to be congruent or incongruent. In congruent conditions, prime and target were semantically congruent (e.g., the prime word ‘high’ preceded the target word ‘above’) and in incongruent conditions, prime and target were semantically less congruent (e.g., the prime word ‘below’ preceded the target word ‘on top’). To rule out repetition priming (Forster, 1998; Norris & Kinoshita, 2008), prime and target were never identical even in congruent conditions.

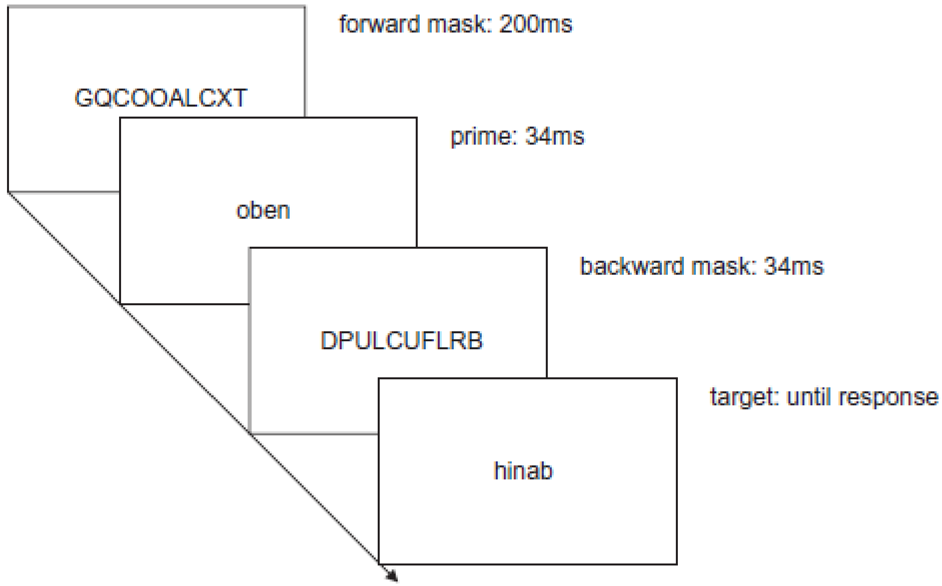

Figure 2: Depicted is an example of an incongruent trial. The arrow depicts the direction of time. Stimuli are not drawn to scale.

All stimuli were presented in gray (24 cd/m2) on a black background (< 1 cd/m2). Each trial started with the presentation of a fixation cross centred on the screen for 750 ms. Next, the forward mask consisting of 10 randomly drawn uppercase letters was shown for 200 ms. Immediately after the forward mask, the prime word was shown for 34 ms (equivalent to two screen refreshes at 59.1 Hz) in lowercase letters. This preceded a backward mask also consisting of 10 randomly drawn capital letters that were shown for 34 ms. Next, the target word stimulus was shown and remained on the screen until the participant pressed one of the response keys. All stimuli were shown centred on the screen with inter-stimulus intervals (ISIs) of 0 ms. Timing of all stimuli was adapted from a prior study that showed little prime visibility (cf. Kiefer & Brendel, 2006).

The experiment was divided into a target response task and a subsequent prime-visibility task. Each task lasted about 45 minutes, with the exception of the letter-word discrimination task concerning the masked stimuli, which took about 15 minutes. During the target response task, participants gave responses that corresponded spatially to the meaning of the visible target word. They pressed the upper key for target words denoting elevated positions or directions toward such positions. They pressed the lower key for target words denoting lower positions or directions toward such positions. The second task was a prime identification task. For 24 participants, the second task required that one key (say the upper key) be pressed in trials in which a word was shown, and the other key (say the lower key) in trials in which a string of identical letters (e.g., “AAAAAAAA”) was shown instead of the prime word. The letter strings always consisted of repeated uppercase letters, but the identity of the letters changed across trials and was randomly chosen from all letters of the alphabet. Note that this visibility task required the introduction of the strings of letters as primes in the judgement task; these were not used in the target response task. For another 24 participants, the second task required, after each trial, judgments of whether they had seen a congruent or an incongruent prime-target pair. This task was run with the stimuli and conditions exactly as in the target response task. This was also true for the final 16 participants who had to give the same kind of responses to the masked prime words as they had given to the targets. In this masked-prime spatial discrimination task, the participants had to provide responses that corresponded spatially to the prime word meaning. In the other two tasks, mappings of judgments to alternative (upward and downward) key presses were balanced across participants, separately for each of the two groups.

The target response task consisted of three blocks, each with 160 trials. This corresponds to 40 repetitions of each of the 2 target types (upward targets; downward targets) × 2 prime types (upward primes; downward primes). The word-letter discrimination task consisted of 160 trials. This corresponds to 80 trials with a masked prime word (conducted in the same manner as in the target response task) and 80 trials with a string of identical letters instead of the prime word. The congruence discrimination task and the spatial prime discrimination task contained exactly the same numbers and sorts of trials as the target response task – that is, these tasks consisted of three blocks with 160 trials each.

During the target response task, after each trial, participants received feedback about errors and if their RT exceeded 1,250 ms. Feedback took 750 ms. Thus, keeping a high accuracy and a fast response speed was mildly rewarded (i.e., saved time). No feedback was given during the visibility tasks.

Results

Target-response task. Data from one participant were lost because he did not perform the visibility task. Of all responses, 3.73% were discarded because RTs deviated by more than 2 standard deviations (SDs) from individual mean RTs. Here and in subsequent experiments, degrees of freedom were adjusted by Greenhouse Geisser ε if Mauchly sphericity tests indicated that the assumption of independent variance across levels of the variables was violated. Normally distributed means were verified using Kolmogorov-Smirnov (K-S) tests.

An initial ANOVA of the means of individual median correct RTs, all $K\text{-}S\ z < 1.15$, all ps > .14, in the target-response task showed that spatial code of the target (upward vs. downward) did not interact, all Fs < 1.00, with the two variables of interest: congruence (congruent vs. incongruent), and group (visibility test 1, 2, or 3). Therefore, data were collapsed across levels of the spatial code variable. A subsequent ANOVA of the mean correct RTs, all $K\text{-}S\ z < 0.88$, all ps > .43, was performed with the remaining within-participant variable of major interest, congruence (congruent vs. incongruent), and the between-participants variable group (visibility test 1, 2, or 3). The group variable was included because if groups differ in the visibility task (to be scrutinized below), looking back at group effects in the target-response task helps to assess whether visibility fosters the masked prime's congruence effect.

The ANOVA revealed significant main effects of congruence, $F(1, 60) = 70.33$, $p < .01$, partial $\eta^2 = 0.54$, and group, $F(2, 60) = 3.41$, $p = .05$, partial $\eta^2 = 0.10$, but no interaction, $F < 1.00$, partial $\eta^2 = 0.01$. Responses were faster in congruent (RT = 728 ms) than in incongruent conditions (RT = 745 ms). RTs tended to be significantly lower for Group 1 (RT = 703 ms) than for Group 3 (RT = 772 ms), $p < .01$, partial $\eta^2 = 0.49$ (Bonferroni corrected for the three groups). However, there were no significant differences between Group 1 and Group 2 (RT = 733 ms), partial $\eta^2 = 0.26$, and between Group 2 and Group 3, partial $\eta^2 = 0.34$, both ps > .59 (uncorrected).

In a corresponding ANOVA of the arc-sine transformed error rates (ERs), all $K\text{-}S\ z < 1.10$, all ps > .23, there were no main effects of congruence, $F(1, 60) = 2.05$, $p = .16$, partial $\eta^2 = 0.03$

(congruent ER = 1.61%; incongruent ER = 1.81%), and group, $F < 1.00$, partial $\eta^2 = 0.02$, and no significant Congruence × Group interaction, $F(2, 60) = 1.07$, $p = .35$, partial $\eta^2 = 0.03$. Thus, speed-accuracy trade-off did not account for the RT congruence effect.

Prime visibility tests. To test whether participants consciously identified the masked primes, we computed *d'*, a sensitive index of stimulus visibility (cf. Reingold & Merikle, 1988). Individual *d'* was computed separately for each task. For Group 1, hits were defined as word primes correctly identified within the context of letter strings; for Group 2, as correct recognition of a congruent relation between prime and target; and for Group 3, as correct judgments of a meaning of a prime indicating an upward spatial location. Correspondingly, false alarms (FAs) were for Group 1, letter strings erroneously judged as words; for Group 2, incongruent trials erroneously taken as congruent trials; and for Group 3, prime words that indicate a downward position judged as being upward. Next, *z*-transformed FA rates were subtracted from *z*-transformed hit rates to obtain *d'* scores (cf. Green & Swets, 1966). The *d'* score becomes zero for chance performance and it can infinitely increase with an increasing number of correct judgments.

The prime was invisible as demonstrated by the participants' mean chance performance. Mean *d'* was not significantly different from zero. It was 0.017, $t(23) = 0.25$, $p = .81$, in the letter-string discrimination task (Group 1), -0.032, $t(23) = -1.31$, $p = .20$, in the congruence discrimination task (Group 2), and 0.024, $t(14) = .83$, $p = .42$, in the spatial prime discrimination task (Group 3). Across groups, mean *d'* was 0.0002, $t(63) = 0.02$, $p = .99$. Correlations between *d'* and *Cohen's D* of the congruence effect (incongruent RT – congruent RT/ pooled congruent+incongruent SD; cf. Dunlop et al., 1996) in the target response task were small and non-significant: $r(24) = .257$, $p = .22$, in Group 1, $r(24) = -.142$, $p = .51$, in Group 2, $r(15) = -.192$, $p = .49$, in Group 3, and $-.15 > r(63) = .12$, $p = .35$, across Groups.

Discussion

In Experiment 1, we found a significant congruence effect of the masked spatial words; that is, in congruent conditions, RTs were lower than in incongruent conditions. In the congruent condition, masked prime words could have both facilitated the processing of the semantic content of the subsequent target word as well as activated the required response. This could be due to either a shared short-term response meaning with the targets as according to the instructions, or due to a long-term response meaning leading to automatic response activation, regardless of the instructions. In the incongruent condition, masked words would have facilitated a processing of a different spatial meaning than that of the target words and would have activated the alternative response in comparison to the target word. After Experiment 1, we cannot tell whether the congruence effect reflected semantic processes, motor activation, or both. This question will be addressed in the subsequent experiments.

The main purpose of Experiment 1 was to establish a working paradigm for studying the ECT with masked spatial words. For that purpose, we wanted to make sure that participants see little if anything of the masked prime words. This was nicely confirmed by the visibility tests. In three different visibility tasks —word-letter discrimination task, spatial prime discrimination task, and congruence discrimination task— participants failed to perform better than chance in discriminating the masked prime words. In addition, we found that the congruence effect in the target response task was not systematically correlated with the judgment accuracy in the visibility test. This latter finding is particularly relevant because it suggests that the better visibility of the masked prime words for some of the participants did not promote the congruence effect in the target RTs. If that would have been the case, we should have found a positive significant correlation between congruence effects in target RTs and judgments, with better visibility leading to stronger congruence effects in the target response task.

Experiment 2

Experiment 2 was our first test of the ECT. We reversed the target-response mapping and now required a spatially non-corresponding response to the visible targets (e.g., press a key below to the target word 'above'). Under these conditions, automatic response activation by the prime's long-term meaning would be working in the opposite direction as compared to the prime's semantic priming effect and as compared to its short-term response meaning or action-triggering effect in Experiment 2 (see Table 1). To note, automatic response activation effects can be found with vertical stimulus code (i.e., presenting stimuli above versus below; e.g., Ansorge & Wuehr, 2004). Thus, an automatic response activation by the position of a congruent masked 'up' prime that is based on the prime's long-term meaning would be, for instance, adding to the costs created by overcoming a similar response tendency for the visible 'up' target. Hence, in the congruent condition, automatic response activation by the prime should further increase RTs. By contrast, the same masked 'up' prime, preceding an incongruent 'down' target, would activate the required upward response (i.e., the correct response that would be required for the 'down' target). Hence, in the incongruent condition, RTs should decrease. This leads to the following predictions. If the masked prime's long-term meaning automatically activates a response toward its signified location as predicted by the ECT, an interaction of the variables' prime-target congruence and target-response correspondence was to be expected, with a smaller prime-target congruence effect under target-response non-corresponding conditions (in Experiment 2a) than under target-response corresponding conditions (in Experiment 1). The same prediction holds if target-response correspondence varies between blocks within the same participants (in Experiment 2b). The difference between a lower congruence effect target-response corresponding relative to target-response non-corresponding conditions should be the larger the stronger the contribution of the prime's response activation to its overall congruence effect.

In contrast to this prediction, if the prime exerts its influence on target responses only via semantic priming, the same congruence effect should be observed in Experiment 2a as in Experiment 1, and regardless of target-response correspondence in Experiment 2b. The same prediction would be made if action-triggering (or direct parameter specification) accounts for the full congruence effect because reverting the target-response mapping means that the reversed short-term response meaning also applies to the masked primes. In fact, the known 'independence' or additivity of influences of (a) direct parameter specification by masked spatial sensory primes and of (b) target-response correspondence on target RTs (cf. Ansorge & Neumann, 2005; Leuthold & Kopp, 1998; Klotz & Neumann, 1999) provides us with a nice alternative benchmark of what to expect if only such task-dependent short-term response meaning accounts for the masked prime's congruence effect. Regarding all of the above, it follows that any combination of action-triggering and semantic priming that created the congruence effect in Experiment 1 should also lead to a similarly sized congruence effect under target-response non-corresponding conditions.

To conclude, any residual congruence effect under the target-response non-corresponding conditions in Experiments 2a and 2b could be due to action-triggering (or direct parameter specification) or semantic priming. (Differentiation between these expected residual congruence effects is the subject of the final Experiment 3.)

Method

Participants. Twenty-four students (12 female) with a mean age of 28 years participated in Experiment 2a, and twenty-four students (9 female) with a mean age of 25 years participated in Experiment 2b.

Apparatus, stimuli, and procedure. These were the same as in Experiment 1, except for the following. In Experiment 2a, the participants had to provide a spatially non-corresponding response to the visible target words' meanings. They had to press a key below the home key if the target word denoted an elevated position and a key above the home key if the target word denoted a lower position. Again, the letter-word discrimination task (visibility test 1 of Experiment 1) was used as a prime visibility test: participants had to decide whether they saw one of the spatial words as a prime or whether they saw a string of identical uppercase letters.

In Experiment 2b, another 24 participants worked through three blocks, one with spatially corresponding responses to the visible targets, one with spatially non-corresponding responses to the visible targets, and one final block of congruence discrimination testing prime visibility. The order of the first two blocks was balanced across participants; the visibility test was last. In Experiment 2b, each of the blocks consisted of 320 trials.

Results

Target response task. Of the responses, 3.93% in Experiment 2a and 1.33% in Experiment 2b were excluded because RTs deviated by more than 2 SDs from the individual means. In the following, we first report the results of an ANOVA with target-response correspondence as a between-participants variable (Experiment 2a vs. Experiment 1), followed by results of an analogue ANOVA with target-response correspondence as a within-participant variable (Experiment 2b).

Experiment 2a. In a comparison of Experiment 1 with Experiment 2a, an ANOVA of the mean correct RTs, with the single within-participant variable congruence (congruent vs. incongruent) and the between-participants variable target-response correspondence (1 vs. 2a), all *K-S z* < 0.71, all *p*s > .69, was significant. This ANOVA confirmed that the congruence effect dropped sharply and significantly. In Experiment 2a's target-response non-corresponding conditions, the congruence effect of 7 ms [incongruent RT (844 ms) – congruent RT (837 ms), $t(23) = 2.11$, $p > .05$] was largely reduced as compared to the congruence effect of 17 ms in Experiment 1's target-response corresponding conditions. This was also reflected in a significant interaction between congruence and target-response correspondence, $F(1, 85) = 7.07$, $p < .01$, partial $\eta^2 = 0.08$. In addition, we observed significant main effects of congruence, $F(1, 85) = 40.85$, $p < .01$, partial $\eta^2 = 0.33$, and of target-response correspondence, $F(1, 85) = 21.73$, $p < .01$, partial $\eta^2 = 0.20$, with RTs higher in target-response non-corresponding (RT = 840 ms) than target-response corresponding conditions (RT = 737 ms). ANOVAs thus confirmed that RTs in the spatially non-corresponding target-response conditions were also significantly higher than in spatially corresponding target-response conditions.

We additionally tested whether correspondence and congruence effects were a function of the RTs by rank ordering the RTs and averaging RTs for each decile of the RT distributions, separately for the levels of the variables target-response correspondence (corresponding vs. non-corresponding) and congruence (congruent vs. incongruent). Prior research indicated that a declining congruence effect across increasing RTs is the fingerprint of a response activation effect of the masked words (cf. Kinoshita & Hunt, 2008) but this was also done to test whether short-lived congruence effects were diminished by longer RTs per se (see also further analyses below).

An ANOVA with the within-participant variables congruence (defined as above) and decile (1^{st} to 10^{th} decile of the RT distribution), and the between-participants variable target-response correspondence (Experiment 1: corresponding vs. Experiment 2a: non-corresponding) confirmed significant main effects of congruence, $F(1, 85) = 20.81$, $p < .01$, partial $\eta^2 = 0.20$, and of target-response correspondence, $F(1, 85) = 17.29$, $p < .01$, partial $\eta^2 = 0.17$, and a significant two-way Congruence × Target-Response Correspondence interaction $F(1, 85) = 9.10$, $p < .01$, partial $\eta^2 = 0.10$. It also led to a (trivial) significant main effect of deciles, $F(9, 765) = 246.18$, $p < .01$, $\varepsilon = .117$, partial $\eta^2 = 0.74$, to a significant Congruence × Decile interaction, $F(9, 765) = 15.54$, $p < .01$, $\varepsilon = .344$, partial $\eta^2 = 0.16$, and to an almost significant Target-Response Correspondence × Decile interaction, $F(9, 765) = 3.24$, $p = .07$, $\varepsilon = .117$, partial $\eta^2 = 0.04$. The three-way interaction was not significant, $F < 1.00$, partial $\eta^2 = 0.01$.

This means that we found the expected decline of the RT congruence effect with increasing RT. Congruence effects were significant among the earlier deciles, but decreased toward the slower responses. This pattern was found in the corresponding (Experiment 1) as well as in the non-corresponding (Experiment 2a) conditions (cf. Figure 3). This, however, meant that we could not discern whether using a non-corresponding target-response mapping diminished congruence effects through the prime's automatic response activation effect and additionally (or independently) slowed RTs, or whether the non-corresponding mapping slowed the responses, and the lower congruence effect was just one consequence of this slowing of the responses. This question will be addressed in Experiment 2b, below.

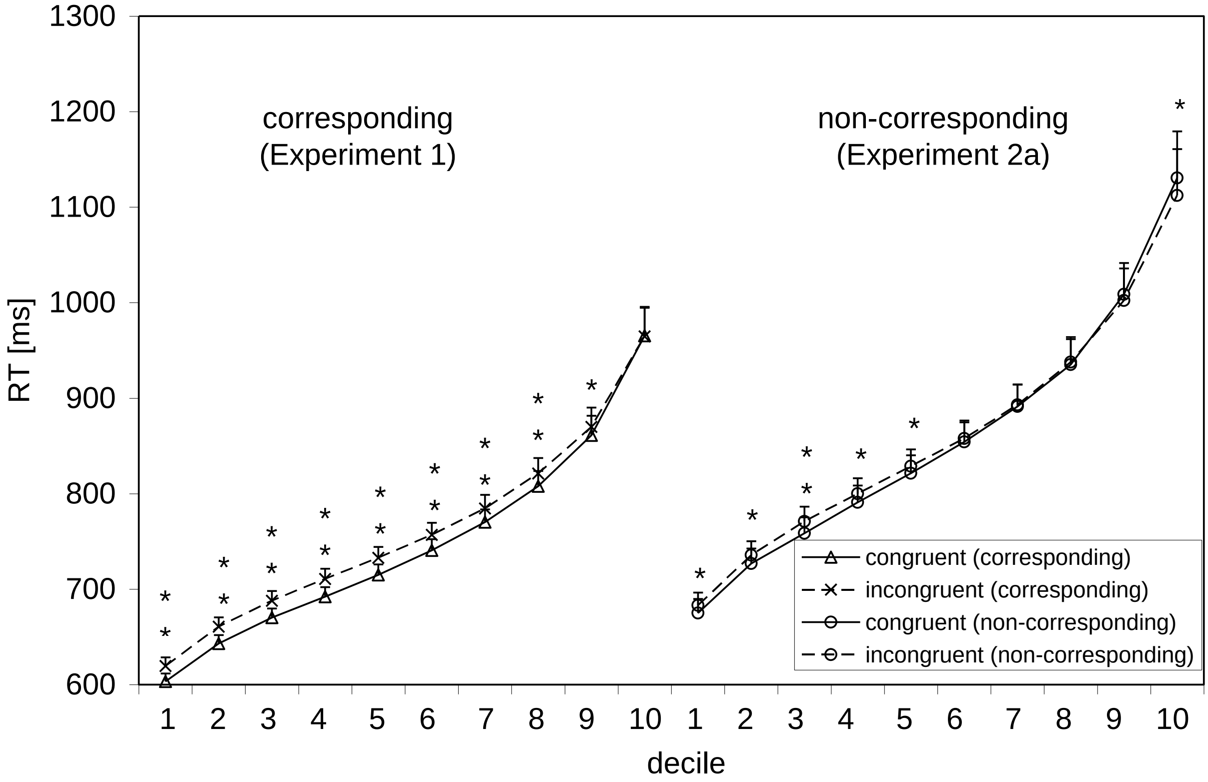

Figure 3: Mean correct Reaction Times (RTs in ms) as a function of prime-target congruence (congruent: straight lines; incongruent: broken lines), target-response correspondence (triangles [left graphs]: target-response corresponding [Experiment 1]; circles [right graphs]: target-response non-corresponding [Experiment 2a]), and decile (1st to 10th) of the RT distribution on the x axis. Vertical bars depict standard errors of the corresponding means. *: significant at $p < .05$; **: significant at $p < .01$.

We also scrutinized the reversed congruence effect (incongruent RT – congruent RT = -19 ms) in the slowest responses in Experiment 2a, which could be seen in Figure 3. This reversal of the congruence effect nicely fits an account of the smaller congruence effect in terms of the prime's automatic response activation because, as explained in the introduction of Experiment 2, the incongruent prime but not the congruent prime would now have activated the required correct response. Therefore, the 15 ms advantage of incongruent over congruent conditions (see Figure 3) that was confirmed in Experiment 2a, $t(23) = 2.20$, $p < .05$, *Cohen's D* = 0.12, makes perfect sense on the basis of the prime's automatic response activation effect.

ANOVAs of the arc-sine transformed error rates with the variables congruence and target-response correspondence, all *K-S z* < 1.25, all *p*s > .09, confirmed the picture. The slower mean correct reactions in target-response non-corresponding conditions than in target-response corresponding conditions were accompanied by a lower mean accuracy as reflected in a significant main effect of target-response correspondence, $F(1, 85) = 44.71$, $p < .01$, $\eta = 0.35$: Mean error rate was 5.99% in non-corresponding conditions and 1.59% in corresponding conditions. In addition, a tendency toward a significant Target-Response Correspondence × Congruence interaction, $F(1, 85) = 3.08$, $p = .08$, $\eta = 0.35$, reflected a tendency towards a reduced congruence effect in non-corresponding (incongruent ER [5.83] – congruent ER [6.15] = –0.32%) as compared to corresponding conditions (incongruent ER [1.70] – congruent ER [1.49] = 0.21%). Therefore, neither the significant RT increment nor the smaller RT congruence effect in non-corresponding as compared to non-corresponding conditions reflected a speed-accuracy trade-off. (The main effect of congruence was not significant, $F < 1.00$.)

Experiment 2b. An ANOVA of the mean correct RTs with the two within-participant variables congruence (congruent vs. incongruent) and target-response correspondence (corresponding vs. non-corresponding), all *K-S z* < 0.88, all *p*s > .43, was conducted. It confirmed the congruence effect's drop, here to 11 ms (incongruent RT [787 ms] – congruent RT [776 ms], $t[23] = 2.81$, $p < .05$), in target-response non-corresponding conditions from 21 ms (incongruent RT [682 ms] – congruent RT [661 ms], $t[23] = 6.48$, $p < .01$) in target-response corresponding conditions. This was again reflected in a significant interaction of Congruence × Target-Response Correspondence, $F(1, 23) = 4.24$, $p = .05$, partial $\eta^2 = 0.16$. In addition, we observed significant main effects of congruence, $F(1, 23) = 34.27$, $p < .01$, partial $\eta^2 = 0.56$, and of target-response correspondence, $F(1, 23) = 53.89$, $p < .01$, partial $\eta^2 = 0.70$, with RTs higher in target-response non-corresponding (RT = 782 ms) than target-response corresponding conditions (RT = 672 ms).

An additional ANOVA with the within-participant variable decile (1st to 10th decile of the RT distribution), confirmed significant main effects of congruence, $F(1, 23) = 26.37$, $p < .01$, partial $\eta^2 = 0.53$, and of target-response correspondence, $F(1, 23) = 47.96$, $p < .01$, partial $\eta^2 = 0.68$, and a significant two-way Congruence × Target-Response Correspondence interaction, $F(1, 23) = 4.54$, $p < .05$, partial $\eta^2 = 0.17$. It also led to the expected significant main effect of decile, $F(9, 207) = 463.18$, $p < .01$, $\varepsilon = .124$, partial $\eta^2 = 0.95$, to a significant Congruence × Decile interaction, $F(9, 207) = 13.31$, $p < .01$, $\varepsilon = .332$, partial $\eta^2 = 0.37$, and to a significant Target-Response Correspondence × Decile interaction, $F(9, 207) = 13.31$, $p < .01$, $\varepsilon = .332$, partial $\eta^2 = 0.37$, partial $\eta^2 = 0.04$. The three-way interaction was not significant, $F < 1.00$, partial $\eta^2 = 0.02$.

Again, congruence effects dropped with increasing RT in both corresponding and non-corresponding conditions (cf. Figure 4). This time, however, the reversed congruence effect among the slowest responses amounted to only -11 ms in Experiment 2b's target-response non-corresponding conditions, $t(23) = 1.10$, $p = .27$, *Cohen's D* = 0.07, and it was accompanied by a smaller numerically reversed congruence effect in the target-response corresponding conditions of -6 ms, $t < 1.00$, *Cohen's D* = 0.07. Therefore, the origin of the reversed congruence effect could be more general than assumed above, and might also reflect active inhibition of the prime's automatically activated responses after a time interval of several hundred milliseconds (cf. Kinoshita & Hunt, 2008; Ridderinkhof, 2002).

In Experiment 2b, we also tested whether individual absolute RTs or individual target-response correspondence effects were predictors of individual congruence effects in target-response non-corresponding conditions. We assumed that the individual target-response correspondence effects that we observed approximately reflected the participants' individual susceptibility to the prime's automatic response activation. If this holds true and if there is an influence of the prime's automatic response activation to the diminution of the congruence effect in non-corresponding conditions, the correspondence effect should be a significant predictor of the congruence effect in the non-corresponding conditions with an inverse relation between both variables.

To test this, we simultaneously entered (1) individual correspondence effects (individual mean non-corresponding RT – individual corresponding RT) and (2) individual average correct RTs as two potential predictors into a function that linearly regressed individual congruence effects (individual mean incongruent RT – individual mean congruent RT) on these two variables, and excluded them step-wise based on a non-significance criterion (p > .1). This linear regression had the form, $x = \beta_y \times y + \beta_z \times z + \varepsilon$, in which x corresponded to the congruence effect (i.e., the dependent variable), y and z to two constants, β_y and β_z, to two corresponding weights of the constants (with constants times weights corresponding to the influences of the two predictors: the correspondence effect and average RT), and ε to a residual error term.

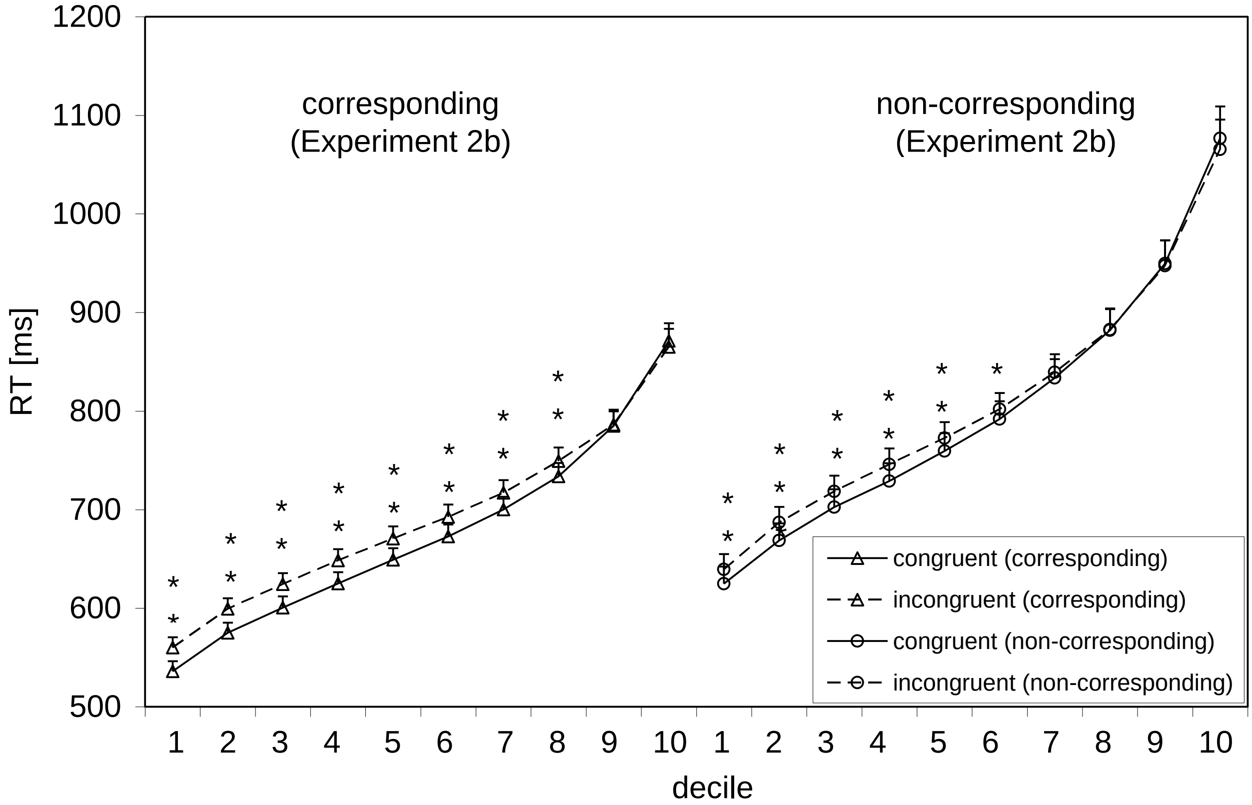

Figure 4: Mean correct Reaction Times (RTs in ms) of Experiment 2b as a function of prime-target congruence (congruent: straight lines; incongruent: broken lines), target-response correspondence (triangles [left graphs]: target-response corresponding; circles [right graphs]: target-response non-corresponding), and decile (1st to 10th) of the RT distribution on the x axis. Vertical bars depict standard errors of the corresponding means.

In line with a genuine contribution of prime-elicited response activation, we found a significant (inverse) relation between correspondence effect and prime-target congruence effect in the non-corresponding conditions, with a model regressing the congruence effect in non-corresponding conditions to the correspondence effect alone, $\beta_y = -.42$, $F(1, 22) = 4.83$. The regression that additionally included the predictor RT failed to become significant, $\beta_y = -.36$, and $\beta_z = -.18$, $F(2, 21) = 2.77$, $p = .09$. A model based on average RT as the sole predictor also failed, $\beta_z = -.32$, $F(1, 22) = 2.43$, $p = .13$.

Arc-sine transformed error rates showed that the slower mean correct reactions in target-response non-corresponding conditions than in target-response corresponding conditions were accompanied by a lower mean accuracy as reflected in a significant main effect of target-response correspondence, $F(1, 23) = 39.00$, $p < .01$, $\eta = 0.63$: Mean error rates were 4.9% in non-corresponding conditions and 1.9% in corresponding conditions. No significant Target-Response Correspondence × Congruence interaction was found, $F(1, 23) = 1.93$, $p = .18$, $\eta = 0.08$, but numerically, congruence effects (incongruent ER – congruent ER) were also larger in corresponding conditions (0.6%) than in non-corresponding conditions (-0.4%). The main effect of congruence was also not significant, $F < 1.00$.

Prime visibility tests.

Experiment 2a. The masked spatial words were invisible: Mean *d'* was 0.052, and not significantly different from zero, $t(23) = 1.136$, $p = .27$. The correlation between *Cohen's D* of the congruence effect in the target response task and the *d'* visibility scores was low and non-significant, $r(24) = .021$, $p = .92$.

Experiment 2b. Mean visibility was also low and *d'* was not significantly different from zero, *d'* = 0.05, $t(23) = 1.31$, $p = .20$. The correlation between *Cohen's D* of the congruence effect in the target response task and the *d'* visibility scores was low and non-significant: it was $r(24) = .16$, $p = .46$, for the target-response corresponding conditions, and $r(24) = -.015$, $p = .94$, for the target-response non-corresponding conditions.

Discussion

Experiment 2 was our first test of the ECT hypothesis. We argued that if word semantics are grounded in sensorimotor representations, we should find response-activation effects based on the prime word's spatial long-term meaning, which are similar to what has been found for visible spatial words (cf. Proctor et al., 2000). In detail, as a benchmark effect for our test, we used known automatic response activation by visible spatial words. This effect is based on long-term meaning. Here, this influence was secured by asking participants to not provide a spatially compatible response to a spatial word. On the contrary, short-term response meaning, as it was defined by the task, required that the participants provide a spatially non-corresponding response to the target. In Experiment 2, a response activation effect based on the masked word's spatial long-term spatial meaning was therefore in the opposite direction as compared to the finally required response to the visible target words in the conditions with a non-corresponding word-response mapping only (see Table 1). Under these conditions, the ECT predicts an interaction between target-response correspondence (with the two steps corresponding and non-corresponding mapping) and prime-target congruence.

We found—fully compatible with this ECT-predicted interaction—a significant reduction of the congruence effect under the target-response non-corresponding conditions as compared with the target-response corresponding conditions. This pattern of results confirmed that part of the congruence effect was brought about by the prime's automatic response activation. This interaction was found regardless of whether the comparison was between participants of Experiments 1 and 2a or within participants of Experiment 2b.

In addition, (spatial or automatic) response activation effects (e.g., Ansorge & Wuehr, 2009; Kinoshita & Hunt, 2008) are short-lived, and are thus inversely proportional to the average time that passes between prime word and response. This was also found in the present experiment. Here, we extended past findings (Kinoshita & Hunt, 2008) by showing that essentially the same pattern is observed with masked prime words activating responses on the basis of their long-term meaning.

Finally, with a regression model, we tested whether individually measured target-response correspondence effects as an approximation to the prime's potential response activation effect, or whether the length of the individual average correct RT was a better predictor of the congruence effect in the non-corresponding conditions. In line with the assumption that the masked prime words automatically activated responses on the basis of their spatial long-term meaning, we found that the size of the individual target-response correspondence effect was a significant predictor of the congruence effect in the non-corresponding condition, and that total individual mean correct RT alone was not. The data are therefore consistent with the ECT. Reverting the target-response mapping to a non-corresponding mapping diminished the congruence effect by means of the prime's automatic response activation.

To conclude, the prediction of an additive contribution of prime-target congruence and target-response correspondence to the RTs was falsified: in the spatially non-corresponding target-response conditions of the present experiment, we observed a significantly smaller prime-target congruence effect than in the spatially corresponding target-response conditions. In that respect, our results violated the predictions based on an explanation of the congruence effect in terms of 'pure' or abstract semantic priming without concomitant response activation. Importantly, this was found even though the primes were virtually invisible.

We also found a residual congruence effect in the non-corresponding conditions. Whether this residual spatial congruence effect could have reflected 'pure' semantic priming without activation of a response, action triggering, or both of these processes, was tested in the final experiment.

Experiment 3

Experiment 3 provided the second of our ECT tests. In Experiment 2, we observed a residual congruence effect in the target-response non-corresponding conditions that could not have been due to responses activated by the prime's long-term spatial meaning. Here, we wanted to test whether this residual congruence effect was based on short-term response meaning as this is determined by the instructions or whether it could have reflected 'pure' semantic priming, without any concomitant response activation.

To study the origin of the residual congruence effect, we used two conditions. In Experiment 3a, we prevented the prime's response activation by its long-term and by its short-term meaning, but we spared its semantic congruence relation to subsequent target words. If grounding sensorimotor representations are necessary for semantic processing, as assumed in the ECT, we might find no evidence for a congruence effect under these preventing conditions. In Experiment 3b, we only blocked the prime's response activation by its long-term meaning, but spared its semantic congruence effect and its response activation through short-term response meaning. According to the ECT, in these conditions, the necessary preconditions for a semantic processing of the prime words would be secured and a congruence effect was to be expected.

In both conditions, we prevented the long-term sensorimotor representations of the prime to exert its influence. Research with clearly visible stimuli has shown that spatial stimulus position code automatically activates responses, only if the participants can also use this particular spatial stimulus code for discriminating between the required alternative responses (Ansorge & Wuehr, 2009, 2004; Wuehr & Ansorge, 2007; Wuehr, Biebl, & Ansorge, 2008). In particular, vertical (up-down) spatial stimulus code automatically activated responses if participants had to discriminate between alternative vertical (upward and downward) responses. However, vertical spatial stimulus code failed to automatically activate a response, if participants had to discriminate between alternative horizontal (leftward and rightward) responses (cf. Ansorge & Wuehr, 2004). Applying a similar logic to the masked primes, we should be able to prevent the prime word's automatic response activation effect and any semantic congruence effect conditional on such automatic response activation, if we require leftward vs. rightward responses to the spatial words. This was done in the present study.

In Experiment 3a, we also prevented action triggering by the prime based on short-term response meaning (cf. Kunde et al., 2003). To that end, we used 'novel' targets – that is, a set of response-relevant target words not overlapping with the set of masked prime words. The target words in Experiment 3a were different from the preceding experiments, while the masked prime words were kept the same. The visible target words were now the number words *one* to *four* and *six* to *nine*. These target number words were chosen to assess a semantic priming effect, which could not be based on the prime's instructed (left or right) response meaning. Note, that numbers have a spatial connotation overlapping with the spatial meaning of our prime words. Numbers can be 'low' or 'high'. In addition, we emphasized this particular spatial meaning of the numbers by our task. Our participants had to discriminate integers as being *above* or *below* five. Because the spatial prime words were the same as before and on the basis of the spatial connotation of smaller numbers as being lower (and also being below five) than larger numbers (being above five) putative congruence levels for pure semantic priming based on abstract spatial codes were as follows: The masked down-prime words should be spatially congruent to the number words below five, and the masked up-prime words should be spatially congruent to the number words above five. Correspondingly, incongruent conditions combined a masked down-prime word with a number word above five or a masked up-prime word with a number word below five.

To the extent that the residual congruence effect in Experiment 2's non-corresponding target-response conditions reflected only an abstract spatial code contributing to the processing of the meaning of spatial (and number) words that is not conditional on underlying grounding sensorimotor representations, a congruence effect was expected to prevail in Experiment 3a (see also Table 1). By contrast, to the extent that the prime's response activation via target-similarity accounted for the residual congruence effect in Experiment 2's non-corresponding conditions, this residual congruence effect was expected to drop in Experiment 3a.

In Experiment 3b, we tested an additional 24 participants who saw the same spatial words as visible targets that we also used as masked primes (and that we used as visible targets in all preceding experiments). Half of these participants pressed a left key in response to a word denoting a position above and a right key in response to a word denoting a position below. For the other participants, the response assignment was reversed. Thus, like in the number-target conditions, in this spatial target condition, we ruled out that automatic long-term response meaning could have contributed to the prime-target congruence effect (cf. Ansorge & Wuehr, 2004). Nevertheless, in this spatial target condition the primes resembled the targets and were therefore response-relevant. Thus, they could have activated one of the instructed responses on the basis of their short-term response meaning (cf. Kunde et al., 2003). In fact, based on the results of Experiments 1 and 2, one would expect a congruence effect of intermediate size, in-between the congruence effects in the preceding experiments in these spatial target conditions (cf. Table 1).

One other priming influence that we had to control for only in Experiment 3b's spatial target conditions was that of orthogonal compatibility. Sometimes rightward responses to up stimuli and leftward responses to down stimuli are faster than leftward responses to up stimuli and rightward responses to down stimuli (e.g., Cho & Proctor, 2003). This orthogonal stimulus-response compatibility effect is a long-term memory effect, too. Thus, we wanted to know whether primes can automatically activate responses via orthogonal compatibility based on long-term spatial meaning in Experiment 3b. If so, we expected to find a congruence effect under orthogonally compatible target-response mapping conditions but not (or even a reversed congruence effect) under orthogonally incompatible target-response mapping conditions. For example, only in the orthogonally compatible conditions, an up-prime's automatically activated rightward response could have facilitated a rightward response to the congruent target but not a leftward response to the incongruent target.

In Experiment 3a, the variable orthogonal compatibility corresponded to the variable SNARC compatibility. The SNARC (spatio-numeric association of response codes) compatibility effect denotes that participants respond faster if pressing a left key for small and a right key for large numbers (in SNARC compatible conditions) than if pressing a right key for small and a left key for high numbers (in SNARC incompatible conditions). The different SNARC compatibility levels are assumed to reflect a mental number line with increasing numbers being represented left to right (cf. Dehaene, 1997). Hence, according to the SNARC principle, locations of visible number targets on this mental number line could be either spatially compatible or incompatible to the required response. As orthogonal compatibility effects show (cf. Cho & Proctor, 2003), however, (part of) the SNARC effect could also be reflecting the more general principle of orthogonal compatibility, with a better fit between right and up, and left and down than between left and up, and right and down.

Method

Participants. Forty-eight students (30 female) with a mean age of 26 years participated in Experiment 3a/b.

Apparatus, stimuli, and procedure. These were the same as in Experiment 1, except for the following differences. First, for 24 participants the target words were different (Experiment 3a). The target words were the German number words '*eins*' to '*neun*' with the exception of the '*fünf*' (in English '*one*' to '*nine*', with the exception of '*five*'). Half of the participants in this number-target condition pressed the left key for numbers below five and the right key for numbers above five, and half of the participants had the reverse S-R mapping.

Second, an additional 24 participants saw the same spatial words as visible targets that we used as masked primes (Experiment 3b). Half of the participants in this spatial target condition pressed a right key in response to up-word targets and a left key in response to down-word targets. This was the orthogonally compatible target-response mapping. This target-response mapping rule was reversed for the other half of the participants. This was the orthogonally incompatible target-response mapping.

Third, the word-letter discrimination task (see visibility test 1 of Experiment 1) was used as a prime visibility test: Participants had to decide whether they saw one of the masked spatial words or whether they saw a string of identical uppercase letters as a masked prime. Half of the participants pressed the left key if they saw a word and the right key if they saw a string of identical letters. This mapping rule was reversed for the other half of the participants.

Analysis. In contrast to the preceding experiments, we ran an additional initial ANOVA of the RTs for the target-response task in the number-target condition, with the two within-participant variables prime (upward; downward) and target (one, two, three, four, six, seven, eight, or nine). This ANOVA was conducted to test whether spatial prime meaning influences at least processing of some of the targets. For example, the congruence effect could increase with the distance between target and the reference number "five". In addition, this ANOVA contained a between-participant variable SNARC compatibility of the target-response mapping.

Results

Number-target response task. Out of all responses, 3.79% were excluded because RTs differed by more than 2 SDs from the individual mean. In the additional initial ANOVA, all $K\text{-}S\ z < 1.00$, all ps > .69, we found a main effect of target, $F(7, 22) = 9.27$, $p < .01$, partial $\eta^2 = 0.30$. This effect means that the larger the distance between a target number and the reference number five and, thus, the less ambiguous a target could be classified as being above or below five, the lower the correct RT. This inverse u-shaped function relating RT to the ordinal position of the target numbers had its apex at the number word *four*. RTs to the target word *four* (RT = 742 ms) were significantly higher than toward all other targets (*one*: RT = 700 ms; *two*: RT = 694 ms; *three*: RT = 716 ms; *six*: RT = 726 ms; *seven*: RT = 711 ms; *eight*: RT = 703 ms; *nine*: RT = 708 ms). In addition, RTs to the target word *six* were significantly higher than to the target words *two*, *seven*, *eight*, and *nine*, and RTs to the target words *three* were higher than to the target word *two*, all significant ps < .05 (Bonferroni-corrected), for all significant differences, *Cohen's Ds* > 0.38.

Most importantly, there was neither a significant main effect of prime, $F < 1.00$, partial $\eta^2 = 0.07$, nor a significant interaction between prime and any other variable, all Fs < 1.50, all ps > .18, all partial $\eta^2 < 0.07$. The main effect of target-response mapping and the other interactions were also non-significant, all ps < 1.00, partial $\eta^2 < 0.05$.

Even with an average non-significant main effect of target-response mapping, responding SNARC compatibly could have led to a steeper drop of the RTs as a function of a variable distance of the target number to *five* because effects of responding SNARC-compatibly would have influenced RTs in the same direction as the distance effect whereas responding SNARC incompatibly would have counteracted the distance effect.

Therefore, we additionally ran an ANOVA with the between-participants variable SNARC compatibility (compatible vs. incompatible) to test whether it interacted with a within-participant variable numerical distance (of the target from five), with steps 1, 2, 3, or 4 positions of distance between target and reference number *five*), and with data collapsed across (1) targets above and below *five* and (2) congruent and incongruent conditions. In line with the SNARC-based expectations, a significant two-way interaction of SNARC Compatibility × Distance, $F(1, 22) = 22.34$, $p < .01$, partial $\eta^2 = 0.34$, reflected a steeper drop of RTs as a function of distance under SNARC compatible (distance 1: RT = 736 ms; 2: RT = 719; 3: RT = 693 ms; 4: RT = 695 ms) than under SNARC incompatible conditions (distance 1: RT = 732 ms; 2: RT = 713; 3: RT = 702 ms; 4: RT = 708 ms).[1]

As a more direct test of the prime-target congruence effect, we compared mean correct RTs from two congruent conditions with mean RTs from the two respective incongruent conditions. For upward primes preceding numbers above *five* (i.e., congruent conditions) collapsed across number targets *six* to *nine*, we observed an RT = 711 ms. For downward primes preceding numbers below *five* (i.e., congruent conditions) collapsed across number targets *one* to *four*, we found an RT = 713 ms. For upward primes preceding numbers below *five* (i.e., incongruent conditions) collapsed across the targets *one* to *four*, we observed an RT = 713 ms. For downward primes preceding numbers above *five* (i.e., incongruent conditions) collapsed across the targets *six* to *nine*, we found an RT = 712 ms. The differences between congruent and incongruent RTs were not significant, for both up and down primes, both $ts(23) < 1.00$, *Cohen's Ds* < 0.04. See also the ANOVA below in which we compared performance in Experiments 3a and 3b by an evaluation of the congruence effect that was more similar to that of the preceding experiments.

For the distributions of the arc-sine transformed error rates, the normality assumption was violated for 17 out of the 32 means, all significant $K\text{-}S\ z > 1.36$, all ps < .05. Therefore, we ran a non-parametric Friedman test on the untransformed error percentages that confirmed significant differences between the conditions, $\chi^2(N = 24,\ d.f. = 15) = 69.27$, $p < .01$. To assess whether congruent and incongruent error rates differed, we next averaged separately for congruent and incongruent conditions across the eight levels of the variable target. Equipped with these means, we ran a non-parametric Wilcoxon test for comparison of summed ranks of congruent versus incongruent means that was far from significant, $Z = 0.60$, $p = .54$. This was also the case if the data were split for SNARC-compatible versus SNARC-incompatible target-response mappings (both Zs < 0.87, both ps > .38). A more fine-grained analysis with pair-wise congruent-versus-incongruent Wilcoxon tests for each target in turn also failed to render any evidence for a congruence effect (all non-significant Zs < 1.10, all non-significant ps > .30).

The origin of the overall significance of the Friedman test was again a target effect. Like in RTs, performance was roughly an inverted u-shaped function of the target's distance to the reference number *five*, with the worst performance for the target number *four*, in detail: *one* (ER = 1.96%), *two* (ER = 1.93%), *three* (ER = 2.86%), *four* (ER = 2.98%), *six* (ER = 2.81%), *seven* (ER = 2.22%), *eight* (ER = 1.59%), and *nine* (ER = 1.69%). Next, we compared means, averaged across levels of the non-significant variable congruence, for each target in turn. These showed spuriously significant differences that were not systematically related to the size of the numeric differences between ERs. Hence, not too much could be learned from the significant ER differences between *seven* and *one*, *seven* and *four*, *seven* and *nine*, and *nine* and *two*, all Zs > 3.19, all ps < .0017 (Bonferroni corrected for 8 choose 2 possible tests).

Finally, we tested whether the error rates of the two groups of target-response mappings, those with a SNARC-compatible mapping and those with a SNARC-incompatible mapping differed from each other, separately for congruent and incongruent conditions by non-parametric Wilcoxon tests. We did not find any differences between the groups, (SNARC-compatible ER = 2.27%;

SNARC-incompatible ER = 2.24%), both *Z*s = 0.23, both *p*s > .84.

Spatial target response task. One participant had to be dropped from the spatial target condition because he did not yield data for the visibility test due to technical failure of the equipment. Out of the remaining participants' responses in the spatial target conditions, 3.75% were excluded because RTs deviated by more than 2 SDs from the mean correct RT. For the purpose of comparing the congruence effects in the number-target condition with that in the spatial target condition, we collapsed data from the number-target condition across the levels of the non-significant variables target-response mapping rule (see also below), prime type, and target number. The ANOVA had a single within-participant variable congruence (congruent vs. incongruent), and the between-participants variable target condition (number targets; spatial targets), all *K-S Zs* < 0.83, all *p*s > .50. This ANOVA confirmed that the congruence effect with the spatial word targets was significantly larger than that with the number word targets as indicated by a significant Congruence × Experiment interaction, $F(1, 45) = 19.79$ $p < .01$, partial $\eta^2 = 0.31$. The main effect of congruence was also significant, $F(1, 45) = 20.21$, $p < .01$, partial $\eta^2 = 0.31$. The main effect of targets was not, $F < 1.00$, partial $\eta^2 = 0.02$.

Subsequent ANOVAs conducted separately for each of the target conditions in turn, revealed that the single variable congruence was far from significant with the number targets, $F(1, 23) < 1.00$, partial $\eta^2 < 0.01$. RT was 711 ms in congruent conditions and it was 711 ms in incongruent conditions. (For the error rates, refer to the analysis above.)

By contrast, in an ANOVA for only the spatial target condition, with the single within-participant variable congruence (congruent vs. incongruent) and an additional between-participants variable orthogonal target-response compatibility (orthogonally compatible: up targets = right responses vs. orthogonally incompatible: down targets = right responses), we found a significant main effect of congruence, $F(1, 22) = 21.81$, $p < .01$, partial $\eta^2 = 0.51$. RTs were 725 ms in congruent and 742 ms in incongruent conditions. There was neither a significant main effect of orthogonal target-response compatibility nor a two-way interaction, both *F*s < 1.00. In orthogonally S-R compatible conditions, the congruence effect amounted to 16 ms, $t(10) = 4.74$, $p < .01$, and in orthogonally S-R incompatible conditions it had a size of 18 ms, $t(11) = 2.94$, $p < .05$.

(The ANOVA of the arc-sine transformed ERs revealed non-significant main effects of congruence, $F[1, 22] = 2.33$, $p = .14$, partial $\eta^2 = 0.10$, orthogonal target-response compatibility, $F < 1.00$, and a non-significant interaction, $F < 1.00$. ERs were only slightly lower under congruent conditions [ER = 2.22%] than under incongruent conditions [ER = 2.61%], both *KS Zs* < 0.85, both *p*s > .49.)

Number-target conditions: prime visibility tests. The masked spatial prime words were marginally visible. Mean *d'* in the number-target condition was 0.099, and significantly different from zero, $t(23) = 1.91$, $p < .05$, in a one-sided *t* test. The correlation of *Cohen's D*s of the RT congruence effect in the target response task and the *d'* scores of the visibility task was low and non-significant, $r(24) = .056$, $p = .80$.

Spatial target conditions: prime visibility tests. The masked primes were residually visible: Mean *d'* was 0.123, and significantly different from zero, $t(22) = 2.68$, $p < .05$. Again the correlation between *Cohen's D*s of the RT congruence effect in the target response task and the *d'* scores of the visibility test was low and non-significant, $r(24) = .009$, $p = .97$.

Discussion

On the basis of the ECT, we expected no significant congruence effect if the masked spatial words were not activating a response. This was the case in the number-target word conditions. In the number-target word conditions, prime words had no short-term response meaning and no potential to activate responses according to their long-term response meaning (cf. Ansorge & Wuehr, 2004). In line with ECT and many prior masked priming studies, no congruence effect was observed under these conditions (cf. Ansorge & Neumann, 2005; Damian, 2001; Kunde et al., 2003; Schlaghecken & Eimer, 2004).

This observation, however, is in contrast with masked word priming studies in which (non-spatial) congruence effects of masked words were found with ‘novel’ visible targets – that is, targets that are not the same as the primes (e.g., Kiefer & Spitzer, 2000; Kiefer, 2002; Naccache & Dehaene, 2001). At present, it is not clear what principles account for the differences between studies (cf. Abrams, 2008; Kiesel et al., 2006; Van den Bussche & Reynvoet, 2007). On the basis of ECT, we propose that whether or not a masked priming effect transfers to novel stimuli could be depending on the kind of grounding representation: It should be enlightening to reconsider each particular instance of transfer or failure of transfer in masked semantic priming studies from the perspective of the grounding sensorimotor representations that are involved.

To elaborate this issue: There is no reason to expect that all semantic representations draw on the same sensorimotor principles of spatial processing that are scrutinized in our tasks (Kiefer, 2005). Instead, previous studies have shown (Hoenig et al., 2008; Sim & Kiefer, 2005) that semantic representations are flexibly composed of different kinds of sensory and motor representations as a function of situational contexts and task demands. As a result, in some cases, purely sensory (e.g., Zwaan et al., 2002) rather than sensorimotor representations could produce a congruence effect (Kinoshita & Hunt, 2008). Words denoting concrete objects, for instance, could be eliciting relatively distinct sensory representations, such that semantic processing of these words would be governed by distinct sensory representations alone (Kiefer et al., 2008).

By contrast to the number-target condition, we expected a congruence effect in the spatial target word condition of Experiment 3b. In this condition, the masked spatial word primes should have activated a response via their short-term response meaning (cf. Kunde et al., 2003). This was exactly what we found. In addition, an explanation in terms of a long-term memory based orthogonal compatibility effect of the masked prime words was ruled out. Whether up stimuli mapped on right responses (and down stimuli on left responses) or whether down stimuli mapped on right responses (and up stimuli on left responses) did not matter for the speed of the responses and for the congruence effect.

One additional result of the current experiment deserves a discussion. We found a significant main effect of the visible target numbers in the RTs and the ERs. Performance was better for less ambiguous targets: Responses were faster and more frequently correct for the extreme numbers than for numbers near the boundary between the categories (numbers near five). This effect is known as the numerical distance effect and is thought to reflect access to an analogue magnitude representation (Dehaene, Bossini, & Giraux, 1993, Kiefer & Dehaene, 1997).

General Discussion

The present study used masked spatial words for studying predictions of the ECT. According to the ECT, semantic processing of words is essentially grounded in sensorimotor representations, as has been confirmed using stimuli presented clearly above the level of awareness (e.g., Kiefer et al., 2008; Zwaan & Taylor, 2006). The present study extended these findings: we showed that subliminal word meaning also activates long-term and short-term sensorimotor representations. In all of our experiments, we used masked subliminal primes and studied prime-target congruence effects. We showed the largest prime-target congruence effect when two kinds of sensorimotor representations contributed to congruence effects: response activation based on the prime’s long-term spatial meaning and its short-term response meaning (Experiment 1). We demonstrated that this congruence effect dropped when the prime’s long-term sensorimotor representation was put in opposition to its short-term response meaning (Experiment 2). Finally, we demonstrated that a prime’s sensorimotor representation based on its short-term response meaning created a residual congruence effect; however, blocking this sensorimotor representation eliminated the congruence effect completely.

These findings suggest that the semantic processing of words, as reflected in the congruence effect, *necessarily* draws upon underlying sensorimotor representations because (a) sensorimotor representations were crucial for the congruence effect and (b) because subliminal prime words elicited these sensorimotor representations even when they were not task-relevant. The latter finding suggests that the words mandatorily elicited sensorimotor representations: it is unlikely that participants intentionally retrieved fitting past sensorimotor representations in response to the masked primes. This is suggested by the general difficulty that participants had in intentionally changing the processing of masked primes as easily as supraliminal words (cf. Dixon, 1970; Forster, 1998; Merikle et al., 2001).

There are of course several caveats in the present study that need to be discussed. First, we used only spatial words. On an empirical level, it is therefore unclear whether other semantic dimensions similarly afford actions and can be processed according to the ECT principles. One reason why we focussed on spatial meaning in the current study was the ubiquity of spatial meaning among different semantic dimensions. Spatial meaning overlaps with such diverse semantic dimensions as tonal pitch (Melara & O'Brien, 1987), affective concepts (cf. Meier & Robinson, 2004; Weger et al., 2008), and numbers (Dehaene, 1992). Although it is not always obvious how this overlap comes about, the ubiquity of spatial dimensions in meaning is nicely in line with the ECT. According to this line of reasoning, space is such a ubiquitous meaning dimension because space provides a commensurate code for linking actions and concepts (cf. Eder & Klauer, 2009). Therefore, the current hypothesis could also be easily tested with word meaning other than spatial meaning (e.g., with affective meaning).

However, it is clear that not all semantic priming effects must rely on sensorimotor representations. Thus, it is possible that such a strong version of the ECT is not as equally supported in other instances. This, however, was not what we wanted to demonstrate. We simply wanted to show was in principle, the ECT also holds for the processing of subliminal words, thereby ruling out that strategic retrieval of past sensorimotor episodes after word recognition is responsible for the ECT evidence.

Second, on a theoretical level, it might be argued that other findings and alternative semantic priming effects that have been found in the past are seemingly brought about without any obvious sensorimotor correlates. For instance, although patients with apraxia can lose the ability to manipulate tools, their semantic knowledge about tool use is spared (Mahon & Caramazza, 2005). In addition, in category priming one word as a prime (e.g., "hawk") facilitates the processing of another word as a target, if that word comes from the same category as the prime (e.g., "eagle") (Quinn & Kinoshita, 2008). Yet, no obvious long-term or short-term response meaning affords the linking of all exemplars of one particular category. How could tool use knowledge in apractic patients and category priming in healthy participants be possible if the ECT were true?

The answer is simple. It is possible that ECT-based knowledge about tool use and ECT-based category priming effects are brought about by purely sensory rather than sensorimotor representations. In the case of apraxia, seeing what others do with a tool could be used for knowledge about tool use. In the case of category priming, similarities between sensory representations of exemplars of a particular category could be underlying category priming. All birds (hawks, eagles, etc.), for instance, have feathers and beaks. Elicitation of past sensory instances from memory could therefore be underlying a masked congruence effect where a sensorimotor representation is not relevant.

In addition, the fact that it is difficult to create a valid measure of a grounding of representation for each particular semantic dimension of word meaning should not be held against the plausibility of the ECT. Instead, this difficulty must be considered as an argument in favour of using spatial words in the current study. In a well-specified situation, each specific spatial word affords particular predictable actions better than others. For instance, in our experiments, with up and down response directions, spatial words such as 'up' or 'down' afford either the one or the other response to a better degree. This means that with spatial words, we can create a valid (maybe even an exhaustive) measure of sensorimotor effects.

Third, our results have implications for theories of masked priming. So far, with few exceptions (cf. Reynvoet, Gevers, & Caessens, 2005), the discussion in masked priming research is stuck on a debate in which a masked stimulus' semantic congruence effect is equated with the prime's long-term (or automatic) meaning effect, and in which the prime's sensorimotor congruence effect is considered to only reflect the prime's short-term or strategic effects (cf. Kunde et al., 2003). This logic is flawed as was shown in the present paper. Theoretically, we argued that it is pointless to distinguish between long-term semantic and short-term sensorimotor processes because semantic meaning can also be created and modified by response meaning on the spot, and because sensorimotor processes are always constrained by a stimulus' long-term meaning because this meaning also reflects past (frequent) sensorimotor processing of that stimulus. In other words, a word can only take on a new response meaning by task instruction because stimulus meaning is, to begin with, fundamentally and inextricably rooted in response meaning. Empirically, we confirmed this notion in the present study by showing that both long-term meaning and short-term meaning of spatial words have sensorimotor correlates.

In summary, our results confirmed the predictions of the ECT. We demonstrated significant similarities between sensorimotor effects of masked spatial words and visible spatial words. We also demonstrated similarities between sensorimotor effects of masked spatial words and masked sensory spatial stimuli. Specifically, the congruence effect of masked spatial words reflected automatic response activation based on long-term meaning as well as task-dependent response activation effects. In the present study, as long as we found any evidence for semantic priming in the form of a significant congruence effect, we also found evidence for sensorimotor effects. As predicted by the ECT, with the suited sensitive tests – that is tasks tapping the response activation effects, semantic and sensorimotor processing of words was found to always coincide. By contrast, an abstract semantic priming effect without any concomitant sensorimotor effect was never observed. These findings are in line with the ECT. Because all of our words were presented subliminally, a strategic retrieval of past sensorimotor episodes in response to the words was unlikely. Thus, our results went beyond previous studies and confirmed a central claim of the ECT that processing of word meaning necessarily draws on grounding sensorimotor processes.

References

Abrams, R. L. (2008). Influence of category size and target set size on unconscious priming by novel words. *Experimental Psychology, 55*, 189-194.

Ansorge, U. (2003). Asymmetric influences of temporally vs. nasally presented masked visual information: Evidence for collicular contributions to nonconscious priming effects. *Brain and Cognition*, *51*, 317-325.

Ansorge, U. (2004). Top-down contingencies of nonconscious priming revealed by dual-task interference. *Quarterly Journal of Experimental Psychology*, *57*A, 1123-1148.

Ansorge, U., & Neumann, O. (2005). Intentions determine the effect of invisible metacontrast-masked primes: Evidence for top-down contingencies in a peripheral cueing task. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 762-777.

Ansorge, U., & Wuehr, P. (2004). A response-discrimination account of the Simon effect. *Journal of Experimental Psychology: Human Perception and Performance, 30*, 365-377.

Ansorge, U., & Wuehr, P. (2009). Transfer of response codes from choice responses to go-nogo tasks. *Quarterly Journal of Experimental Psychology*, *62*, 1216-1235.

Bargh, J. A., Chen, M., & Burrows, L. (1996). Automaticity of social behavior: Direct effects of trait construct and stereotype activation on action. *Journal of Personality and Social Psychology*,*71*, 230–244.

Barsalou, L., W. (1999). Perceptual symbol systems. *Behavioural and Brain Sciences, 22,* 577-660.

Breitmeyer, B., Ogmen, H., & Chen, J. (2004). Unconscious priming by color and form: Different processes and levels. *Consciousness and Cognition*, *13*, 138-157.

Breitmeyer, B. G., Ro T., & Singhal N. S. (2004). Unconscious color priming occurs at stimulus- not percept-dependent levels of processing. *Psychological Science*, *15*, 198-202.

Bridgeman, B., Lewis, S., Heit, G., & Nagle, M. (1979). Relation between cognitive and motor-oriented systems of visual position perception. *Journal of Experimental Psychology: Human Perception and Performance, 5*, 692-700.

Cheesman, J., & Merikle, P. M. (1985). Word recognition and consciousness. In D. Besner, T. G. Waller, & G. E. MacKinnon (Ed.), *Reading research: Advances in theory and practice* (pp. 311-352). New York, NY: Academic Press.

Cho, Y. S., & Proctor, R. W. (2003). Stimulus and response representations underlying orthogonal stimulus-response compatibility effects. *Psychonomic Bulletin & Review*, *10*, 45-73.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82*, 407-428.

Damian, M. F. (2001). Congruity effects evoked by subliminally presented primes: Automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 154-164.

Dehaene, S. (1992). Varieties of numerical abilities. *Cognition*, *44*, 1-42.

Dehaene, S. (1997). *The number sense*. New York: Oxford University Press.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, *122*, 371-396.

De Jong, R., Liang, C.-C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus response correspondence. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 731-750.

Dimberg, U., Thunberg, M., & Elmehed, K. (2000). Unconscious facial reactions to emotional facial expressions. *Psychological Science*, *11*, 86-89.

Dixon, N. F. (1970). *Subliminal perception – the nature of a controversy*. New York: McGraw-Hill.

Dunlop, W. P., Cortina, J. M., Vaslow, J. B., & Burke, M. J. (1996). Meta-analysis of experiments with matched groups or repeate-measures designs. *Psychological Methods*, *1*, 170-177.

Eder, A. B., & Klauer, K. C. (2009). A common-coding account of the bi-directional evaluation-behavior link. *Journal of Experimental Psychology: General*, *138*, 218-235.

Eimer, M., & Schlaghecken, F. (1998). Effects of masked stimuli on motor activation: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1737-1747.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*, 143-149.

Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 680-698.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review, 9*, 558-565.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York, NY: Wiley.

Greenwald, A. G., Draine, S. C. & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science*, *273*, 1699-1702.

Helbig, H. B., Graf, M., & Kiefer, M. (2006). The role of action representations in visual object recognition. *Experimental Brain Research, 174*, 221-228.

Helbig, H. B., Steinwender, J., Graf, M., & Kiefer, M. (2010). Action observation can prime visual object recognition. *Experimental Brain Research*.

Hoenig, K., Sim, E.-J., Bochev, V., Herrnberger, B., & Kiefer, M. (2008). Conceptual flexibility in the human brain: Dynamic recruitment of semantic maps from visual, motion and motor-related areas. *Journal of Cognitive Neuroscience, 20*, 1799-1814.

Kaschak, M. P., & Glenberg, A. M. (2000). Constructing meaning: the role of affordances and grammatical constructions in sentence comprehension. *Journal of Memory and Language, 43,* 508-529.

Kiefer, M. (2002). The N400 is modulated by unconsciously perceived masked words: Further evidence for a spreading activation account of N400 priming effects. *Cognitive Brain Research, 13*, 27-39.

Kiefer, M., & Brendel, D. (2006). Attentional modulation of unconscious semantic processes: Evidence from event-related potentials in masked priming paradigm. *Journal of Cognitive Neuroscience, 18,* 1-15.

Kiefer, M., & Dehaene, S. (1997). The time course of parietal activation in single-digit multiplication: Evidence from event-related potentials. *Mathematical Cognition, 3,* 1-30.

Kiefer, M., Sim, E.-J., Herrnberger, B., Grothe, J., & Hoenig, K. (2008). The sound of concepts: Four markers for a link between auditory and conceptual brain systems. *The Journal of Neuroscience, 28*, 12224–12230.

Kiefer, M., Sim, E.-J., Liebich, S., Hauk, O., & Tanaka, J. W. (2007). Experience-dependent plasticity of conceptual representations in human sensory-motor areas. *Journal of Cognitive Neuroscience, 19,* 525-542.

Kiefer, M., & Spitzer, M. (2000). Time course of conscious and unconscious semantic brain activation. *NeuroReport*, *11*, 2401-2407.

Kiefer, M., & Spitzer, M. (2001). The limits of a distributed account of conceptual knowledge. *Trends in Cognitive Sciences, 5,* 469-471.

Kiefer, M. (2005). Repetition priming modulates category-related effects on event-related potentials: Further evidence for multiple cortical semantic systems. *Journal of Cognitive Neuroscience, 17,* 199-211.

Kiesel, A., Kunde, W., Pohl, C., & Hoffmann, J. (2006). Priming from novel masked stimuli depends on target set size. *Advances in Cognitive Psychology*, *2*, 37-45.

Kinoshita, S., & Hunt, L. (2008). RT distribution analysis of category congruence effects with masked primes. *Memory & Cognition*, *36*, 1324-1334.

Klotz, W., & Neumann, O. (1999). Motor activation without conscious discrimination in metacontrast masking. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 976-992.

Kunde, W., Kiesel, A., & Hoffmann, J. (2003). Conscious control over the content of unconscious cognition. *Cognition*, *88,* 223-242.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility - A model and taxonomy. *Psychological Review, 97*, 253-270.

Lleras, A., & Enns, J. T. (2004). Negative compatibility or object updating? A cautionary tale of mask-dependent priming. *Journal of Experimental Psychology: General*, *133,* 475-493.

Lleras, A., & Enns, J. (2005). Updating a cautionary tale of masked priming: A reply to Klapp (2005). *Journal of Experimental Psychology: General*, *134*, 436-440.

Leuthold, H., & Kopp, B. (1998). Mechanisms of priming by masked stimuli: Inferences from event-related brain potentials. *Psychological Science, 9*, 263-269.

Lu, C.-H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review*, *2*, 174-207.

Machery, E. (2007). Concept empiricism: A methodological critique. *Cognition*, *104*, 19-46.

Mahon, B. Z., & Caramazza, A. (2005). The orchestration of sensory-motor systems: clues from neuropsychology. *Cognitive Neuropsychology, 22,* 480-494.

Martin, A., & Chao, L. L. (2001). Semantic memory and the brain: Structure and processes.

Current Opinion in Neurobiology, 11, 194-201.

Masson, M. E., Bub, D. N., & Newton-Taylor, M. (2008). Language-based access to gestural components of conceptual knowledge. *Quarterly Journal of Experimental Psychology, 61,* 869-882.

Marcel, A. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology*, *15*, 197-237.

McRae, K., & Boisvert, S. (1998). Automatic semantic similarity priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24,* 558-572.

Meier, B.P., & Robinson, M.D. (2004). Why the sunny side is up. Associations between affect and vertical position. *Psychological Science, 15*, 243-247.

Melara, R. D., & O'Brien, T. P. (1987). Interaction between synesthetically corresponding dimensions. *Journal of Experimental Psychology: General*, *116*, 323-336.

Merikle, P. M., Smilek, D., & Eastwood, J. D. (2001). Perception without awareness: Perspectives from cognitive psychology. *Cognition*, *79*, 115-134.

Naccache, L., & Dehaene, S. (2001). Unconscious semantic priming extends to novel unseen stimuli. *Cognition*, *80*, 215-229.

Naccache, L., Blandin, E., & Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science*, *5*, 416-424.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading of activation and limited-capacity attention. *Journal of Experimental Psychology: General*, *106*, 226-254.

Neumann, O. (1990). Direct parameter specification and the concept of perception. *Psychological Research*, *52*, 207-215.

Neumann, O., & Klotz, W. (1994). Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification? In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 123-150). Cambridge, MA: MIT Press.

Niedenthal, P. M. (2007). Embodying Emotion. *Science*, *316*, 1002-1005.

Niedenthal, P.M., Barsalou, L.W., Winkielman, P., Krauth-Gruber, S., & Ric, F. (2005). Embodiment in attitudes, social perception, and emotion. *Personality and Social Psychology* Review, 9, 184–211.

Norris, D., & Kinoshita, S. (2008). Perception as evidence accumulation and Bayesian inference: Insights from masked priming. *Journal of Experimental Psychology: General*, *137*, 434-455.

Plaut, D. C., & Booth, J. R. (2000). Individual and developmental differences in semantic priming: Empirical and computational support for a single-mechanism account of lexical processing. *Psychological Review*, *107*, 786-823.

Proctor, R. W., Marble, J. G., Vu, K.-P. L. (2000). Mixing incompatibly mapped location-relevant trials with location-irrelevant trials: Effects of stimulus-mode on the reverse Simon effect. *Psychological Research*, *64*, 11-24.

Proctor, R. W., & Vu, K.-P. L. (2002). Mixing incompatibly mapped location-irrelevant trials and location-relevant trials: Influence of stimulus mode on spatial compatibility effects. *Memory & Cognition*, *30*, 281-293.

Quinn, W. M., & Kinoshita, S. (2008). Congruence effect in semantic categorization with masked primes with narrow and broad categories. *Journal of Memory and Language*, *58*, 286-306.

Reingold, E. M. & Merikle, P. M. (1988). Using direct and indirect measures to study perception without awareness. *Perception & Psychophysics*, *44*, 563-575.

Richardson, D., & Matlock, T. (2007). The integration of figurative language and static depictions: An eye movement study of fictive motion. *Cognition*, *102*, 129-138.

Reynvoet, B., Gevers, W., & Caessens, B. (2005). Unconscious primes activate motor codes through semantics. Journal of Experimental Psychology: Learning, Memory, and *Cognition*, *31*, 991-

1000.

Ridderinkhof, K. R. (2002). Activation and suppression in conflict tasks: Empirical clarification through distributional analyses. In B. Hommel & W. Prinz (Eds.), *Attention & Performance, Vol. XIX: Common mechanisms in perception and action* (pp. 494-519). Oxford: Oxford University Press.

Schlaghecken, F., & Eimer, M. (1997). The influence of subliminally presented primes on response activation. *Sprache und Kognition, 16,* 166–175.

Schlaghecken, F., & Eimer, M. (2004). Masked stimuli can bias “free” choices between response alternatives. *Psychonomic Bulletin & Review, 11,* 463–468.

Schmidt, T. (2002). The finger in flight: Real-time motor control by visually masked color stimuli. *Psychological Science*, *13*, 112-117.

Schmidt, T., & Vorberg, D. (2006). Criteria for unconscious cognition: Three types of dissociation. *Perception & Psychophysics*, *68*, 489-504.Simon, J. R. (1990). The effect of an irrelevant directional cue on human information processing. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus-response compatibility: An integrated perspective* (pp. 31-88). North-Holland: Elsevier.

Sim, E.-J., & Kiefer, M. (2005). Category-related brain activity to natural categories is associated with the retrieval of visual features: Evidence from repetition effects during visual and functional judgments. *Cognitive Brain Research, 24*, 260-273.

Van den Bussche, E., & Reynvoet, B. (2007). Masked priming effects in semantic categorization are independent of category size. *Experimental Psychology*, *54*, 225-235.

Weger, U., Meier, B. P., Robinson, M. D., & Inhoff, A. W. (2007). Things are sounding up: Affective influences on auditory tone perception. *Psychonomic Bulletin & Review*, *14*, 517-521.

Wuehr, P., & Ansorge, U. (2007). A Simon effect in memory retrieval: Evidence for the response-discrimination account. *Psychonomic Bulletin & Review, 14*, 984-988.

Wuehr, P., Biebl, R., & Ansorge, U. (2008). Selectivity of spatial and nonspatial S-R correspondence effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34,* 533-545.

Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Language comprehenders mentally represent the shapes of objects. *Psychological Science*, *13*, 168-171.

Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: motor resonance in language comprehension. *Journal of Experimental Psychology: General*, *135*, 1-11.

Footnotes

[1]We are grateful to one of the reviewers for pointing this prediction out to us.

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Supported by Deutsche Forschungsgemeinschaft Grant An 393/3-2 to Ulrich Ansorge, An 393/5-1 to Ulrich Ansorge, Werner Klotz and Ingrid Scharlau, Ki 804/3-1 and Ki 804/5-1 to Markus Kiefer within the Research Network “Neuro-Cognitive Mechanisms of Conscious and Unconscious Visual Perception” (PAK 270). Thanks to Sachiko Kinoshita and two anonymous Reviewers for excellent comments on a previous version of the manuscript, and to Pablo Tinio for corrections and proof reading.

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5. No Conflict Control in the Absence of Awareness

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Journal Publication Citation:

Ansorge, U., Fuchs, I., Khalid, S., & Kunde, W. (2011). No Conflict Control in the Absence of Awareness. *Psychological Research, 75,* 351–365. (DOI: 10.1007/s00426-010-0313-4)

Abstract

In the present study we tested whether control over the impact of potentially conflicting information depends on awareness of that conflicting information. In Experiment 1 participants performed a response-priming task, with either masked or unmasked primes. Prime awareness was assessed on a trial-by-trial basis. A typical conflict control pattern, with reduced priming effects following incongruent rather than congruent primes in the preceding trial was found. Yet, this pattern was obtained only when the prime information was visible and not when it was invisible. With invisible primes the effect did not occur, even when participants accidently judged the prime information correctly. Importantly, this confinement of the conflict adaptation effect to unmasked primes occurred despite identical prime processing times with and without masking- a variable that was confounded with prime awareness in previous studies. In Experiment 2 a similar data pattern was found for judgment times regarding the congruency of prime-target pairs. Altogether the results support the conclusion that awareness of visual primes is important for controlling conflict in visuo-motor processing.

Introduction

In human psychology, exerting one's will is sometimes considered to be conditional on preceding awareness. In line with that assumption, authors found that aware visual perception was a precondition for subsequent willing modification of processing of visual stimuli (Greenwald, Draine, & Abrams, 1996; Kunde, 2003; van Gaal, Lamme, & Ridderinkhoff, 2010). This conclusion was based on experimental results showing more response-conflict control after response conflict was elicited by a visible stimulus of which participants were aware than by an invisible stimulus of which participants remained unaware. In fact, conflict control was completely eliminated in one study, if subliminal conflict-eliciting stimuli were presented below the objective threshold of awareness (Kunde, 2003). The same conclusion is also backed up by the observation that subliminal conflict fails to activate the anterior cingulate cortex (Dehaene et al., 2003), a region involved in the monitoring of conflict (cf. Botvinick et al., 1999).

This critical role of awareness for conflict control, however, is not certain because of two confounds. First, in prior studies, participants had more time to process visual stimuli in the aware than in the unaware conditions and, secondly, conflict control was assessed based on a larger ratio of correctly than incorrectly judged conflict-eliciting stimuli in aware than in unaware modes (Frings & Wentura, 2008; Greenwald et al., 1996; Kunde, 2003; van Gaal et al., 2010).

To understand this, we start with a brief description of the evidence for conflict control. Prior research studied conflict control by means of the participants' strategic adjustment of visual sensorimotor processing to a recently seen response-interfering or response-facilitating but task-irrelevant visual stimulus (cf. Gratton, Coles, & Donchin, 1992; Stürmer et al. 2002; Wühr & Ansorge, 2005). In each trial of such an experiment, the participant was presented with two visual stimuli, a task-irrelevant prime (or distractor) and a task-relevant target.

Studies of the role of awareness for conflict control typically used a sequence of an irrelevant prime preceding a relevant target. In conditions of low conflict, the relevant target and the preceding irrelevant prime had the same response meaning. This was called the congruent condition. In conditions of high conflict, the prime and the target had opposite response meanings. This was the incongruent condition. For instance, in Kunde (2003) targets were rightwards or leftwards pointing arrows, and participants had to press the right button for a rightwards pointing target arrow and the left button for a leftwards pointing target arrow only. An irrelevant prime arrow by contrast had to be ignored. In low-conflict or congruent conditions, the target-preceding prime arrow pointed into the same direction as the target arrow. For instance, a rightwards pointing arrow as a prime preceded a rightwards pointing arrow as a target. In high-conflict or incongruent conditions, the prime arrow pointed into the alternative direction as compared to the target arrow. For instance, a rightwards pointing arrow as a prime preceded a leftwards pointing arrow as a target.

Although the prime-target sequences were equally likely congruent and incongruent and, thus, participants were well advised to ignore the prime, participants process these primes to some extent. This is reflected in a congruence effect, with better performance in congruent than incongruent conditions. Corroborating prior research (Marcel, 1983), researchers found a congruence effect of visible as well as invisible primes (e.g., Kunde, 2003). In the unaware conditions, the visual primes were backward masked (cf. Breitmeyer & Ogmen, 2006), that is, a visible mask was shown at the prime's position and with so small an interval after the prime that the mask interrupted processing of the prime (or and made the prime invisible.

The congruence effect of the prime presumably reflected sensorimotor activation (cf. Eimer & Schlaghecken, 1998; Leuthold & Kopp, 1998; Vorberg et al., 2003). In congruent conditions, prime and target had the same response meaning, so that the motor activation by the prime facilitated selection of the required response, whereas in incongruent conditions, the prime had a different response meaning than the target, so that a prime-activated response conflicted with the selection of the required response. In conditions in which participants judged the meaning of words (cf. Frings & Wentura, 2008; Greenwald et al., 1996) the degree of the semantic fit between the prime meaning and the target meaning could additionally or alternatively account for (part of) the congruence effect, with incongruent prime words interfering with the recognition of the subsequent target word's meaning (in comparison to meaning-congruent prime and target words) (cf. Kiefer & Spitzer, 2000).

In line with prior studies of conflict control, researchers found that participants exerted control over the degree to which they processed the visible prime as a consequence of prime-elicited conflict (e.g., Greenwald et al., 1996; Kunde, 2003): Participants were more reluctant to process the visible prime if they just saw an interfering or incongruent prime in the preceding trial. If a participant had just seen a conflict-eliciting or incongruent prime in a trial *n-1*, the participant suppressed prime processing in the subsequent trial *n*. This conflict-elicited control (henceforth, called 'conflict control') over prime processing was observed in comparison to congruent trials. After congruent trials, no control in the form of a suppression of prime processing took place. This was reflected in an interaction between the two variables prime-target congruence in trials *n-1* and *n*. The congruence effect in trial *n* was larger after a preceding congruent trial *n-1* than after a preceding incongruent trial *n-1*. In the following, we will use the term 'Gratton effect' for this interaction (named after Gratton et al., 1992).

It is believed that the Gratton effect reflects a form of adaptive control of processing of the irrelevant primes based, for example, on an ancillary monitoring mechanism (AMM; see also Carter & Van Veen, 2007; Gratton et al., 1992; Stürmer et al., 2002; for alternative views see van Steenbergen, Band, & Hommel, 2009; Wendt, Kluwe, & Peters, 2006). According to this explanation, if AMM detects an irrelevant stimulus (here: a prime) that leads to conflict because it hinders correct response selection (e.g., in an incongruent trial *n-1*), participants exert control via a gating mechanism that focuses attention more narrowly on the target and better excludes prime processing in a subsequent trial *n*. As a consequence, the congruence effect based on the relation between irrelevant prime and target in trial *n* is small after an incongruent trial *n-1*. By contrast, if AMM detects an irrelevant stimulus that facilitates correct response selection (e.g., in a congruent trial *n-1*), the participant exerts control in the form of an opening of the same attentional gate to distribute attention more broadly and encompass prime and target in trial *n*. As a consequence, the prime-target congruence effect in trial *n* is large after a congruent trial *n-1*.

In line with the assumption that the participants' awareness of the stimulus (or stimulus visibility) of the conflict-eliciting incongruent prime could be crucial for conflict control, van Gaal et al. (2010) found that the Gratton was stronger after trials with a visible prime than after trials with an invisible prime, and Kunde (2003) and Greenwald et al. (1996) found the Gratton effect selectively after trials with a visible prime. Kunde (2003) found that with invisible primes, the congruence effect in trial *n* was equally strong after preceding congruent and incongruent trials *n-1*. However, as mentioned above there are two caveats to the conclusion that these findings corroborate the connection between awareness and control.

First, in prior research the prime-target interval (e.g., Kunde, 2003) or the prime duration (e.g., Kunde, 2003; van Gaal et al., 2010) was longer with visible than with invisible primes. As explained, backward masking was used to prevent prime visibility. Backward masking of the prime by a subsequent mask is most efficient with relatively small prime-mask intervals and decreases with longer prime-mask intervals (Alpern, 1953; Breitmeyer & Ogmen, 2006; Vorberg et al., 2003). Therefore, varying the interval between prime and masks and using the target as a mask (cf. Kunde, 2003; van Gaal et al., 2010) or presenting the target always after the mask (cf. Greenwald et al., 1996) rendered primes more or less visible but at the same time confounded influences of visibility with that of prime-target interval. As a consequence of the prime-target interval or prime duration manipulation, participants had more time to process the primes (prior to the targets) in aware than unaware conditions (although the prime-target interval in and by itself seems not to affect the degree of conflict control if visible primes and targets are used, cf. Frings & Wentura, 2008). No wonder that (a) prime discrimination was better in long than short prime-mask interval conditions and that (b) the prime's Gratton effect was also stronger in visible than invisible conditions.

Moreover, prime-target intervals can have a strong impact on (1) the size of the sensorimotor prime-target congruence effect and (2) the size of inter-trial effects. Concerning influence (1), increasing the prime-target interval has the power to increase (Vorberg et al., 2003) but also to decrease or even reverse the congruence effect (e.g., Eimer & Schlaghecken, 1998; Lingnau & Vorberg, 2005) and, as a consequence, to also (2) modify any inter-trial interaction conditional on the congruence effect (in the preceding trial). This was shown in a study by Vorberg (2009) with masked arrows as primes and visible targets as in Kunde (2003).

In the current study, to rule out that different prime durations or prime-target intervals were responsible for how strong a Gratton effect is, we varied visibility by means of either presenting or not presenting a backward mask after the prime, but by keeping the prime duration and the prime-target interval the same under masked and unmasked conditions. If conflict control in the form of a Gratton effect depends on awareness of the stimulus or stimulus visibility, we should find the Gratton effect in visible (unmasked) but not in invisible (masked) priming conditions. If, however, the prime duration or the prime-target interval is responsible for whether or not the Gratton effect can be found, the Gratton effect should be the same in visible (masked) priming conditions as in invisible (unmasked) priming conditions (Vorberg, 2009).

In addition, as a consequence of the higher task difficulty in the unaware than in the aware conditions of prior studies (Greenwald et al., 1996; Kunde, 2003; van Gaal et al., 2010), in unaware conditions evidence for conflict control was based on equal amounts of preceding trials, with incorrectly and correctly judged primes, whereas in aware conditions, evidence for conflict control was based on a larger amount of preceding trials, with correctly than incorrectly judged primes. This was reflected in the performance differences between unaware and aware conditions in tasks in which participants judged the identity of either masked or less masked primes, respectively. In these judgment tasks, participants gave a larger ratio of correct prime judgments in the aware (e.g., the long prime-target interval) condition than in the unaware (e.g., the short prime-target interval) condition. Evidently, researchers thought that judgment performance in the masked condition was so low that the correct judgments in the short-interval conditions must have reflected chance performance, too. As a consequence, researchers like Kunde (2003) did not care about different amounts of correctly judged and thus potentially seen primes in unaware (or masked) vs. aware (or less masked) preceding trials when assessing the Gratton effect.

However, it is possible that regardless of the participants' awareness of the prime identities, the lack of a Gratton effect in the unaware conditions entirely reflected the participants' beliefs about what they saw in a preceding trial rather than what they actually saw in a preceding trial. Besides blocking of the perception of the prime, a mask creates various subjective visual impressions of a masked stimulus (cf., Polat & Sagi, 2007; for a more general argument, see also Rensink, 2000). Some authors even held the participant's resulting erroneous subjective belief about seeing a particular masked prime responsible for the prime's congruence effect in the first place (cf. Kouider & Dupoux, 2004). According to this logic, a Gratton effect should be found in those trials in which the primes were accurately judged in the preceding trial. However, an opposite Gratton effect would be obtaining in those trials in which the participants inaccurately judged a prime in the preceding trials, because such an incorrect judgment means that the participants believed an objectively realized congruent condition to have been an incongruent condition, and an objectively realized incongruent condition to have been a congruent condition. According to this logic, an equal number of correctly and incorrectly judged primes in the unaware conditions can lead to equal ratios of conflict control after congruent and incongruent trials. By contrast, a higher number of correctly judged primes in the aware conditions will always lead to a larger ratio of conflict control after incongruent trials.

In line with the theoretical possibility that the participants' beliefs rather than their awareness of the stimuli can drive the Gratton effect, van Steenbergen et al. (2009) found that incentives rather than the degree of conflict per se was responsible for Gratton effects. Van Steenbergen et al. (2009) rewarded their participants higher after incongruent trials (with higher conflict) than after congruent trials (with lower conflict) and, as a consequence, reversed the typical Gratton effect into a lower congruence effect after congruent than incongruent preceding trials.

To rule out the possibility that a mixture of correct and false beliefs about the prime-target relation in the preceding trial (corresponding to correct and false prime judgments in the preceding trial) falsely suggested a lower Gratton effect in previous unaware priming conditions, we asked our participants to judge the primes in each trial of our experiments. In this manner we can selectively look at those trials in which participants correctly judge the prime-target sequence in a preceding trial, even in unaware conditions.

If it is true that the participants' low awareness of the conflicting prime in masked conditions reflected chance performance with the correctly judged primes, too, and if the Gratton effect depends on this kind of awareness (or visibility) and not on the participants' beliefs of what they saw, we should find a lower or even no Gratton effect at all in masked conditions, even if we only look at only those trials in which the prime was correctly judged in the preceding trial. However, if it does not matter whether the participants were aware of the prime but rather what they believe they saw, or if the participants' correct judgments about the masked primes reflected residual prime visibility, a Gratton effect should be found in those trials of the masked condition in which participants accurately judged the prime's identity in the preceding trial.

Finally, in Experiment 1, we also tested whether conflict control is domain specific or whether it is domain general. According to domain-general theories of conflict control, conflict in one dimension (or task) can elicit control of conflict in an alternative dimension (or task, cf. Botvinick, Cohen, & Carter, 2004; Kunde & Wühr, 2006; but see, e.g., Davelaar & Stevens, 2009; Kiesel, Kunde, & Hoffmann, 2006). Here, we tested whether conflict elicited in one domain by relations between the visible target's meaning and the responses affected the regulation of the conflict in an alternative domain, that is, between invisible prime and target. More or less target-response conflict was elicited by requiring the participants to give spatially corresponding responses to visible targets in one block (i.e., up responses to up targets and down responses to down targets) but spatially non-corresponding responses in another block (i.e., up responses to down targets and down responses to up targets). Prior research showed that responses are faster in corresponding conditions in which the target meaning and the response meaning overlap than in non-corresponding conditions (cf. Lu & Proctor, 1995). This is due to response conflict. The target activates a response based on its long-term meaning (De Jong, Liang, & Lauber, 1994). This response is in accordance with the required response in corresponding blocks, thereby, facilitating the correct response.

However, in the non-corresponding conditions, the response elicited by the target word’s meaning is in conflict with the finally required response, thereby delaying execution of the correct response.

If a domain-general conflict mechanism is at work and target-response non-correspondence elicits control of the conflict incurred by incongruent primes, too, this should lead to down-regulated prime processing and, hence smaller congruence effects in the non-corresponding than in the corresponding condition. Again, if conflict control depends on stimulus awareness, however, we might find evidence for domain-general conflict control only in the aware but not in the unaware priming condition. In addition to what we already suspect on the basis of the existing studies, a lack of domain-general conflict control in unaware conditions would point to a role of awareness as a necessary precondition not only for eliciting but also for applying conflict control. The reason for this is that domain-general conflict on the basis of target-response correspondence should be always elicited, in unaware (masked) and aware (visible) priming conditions, because participants are always aware of the target. If, however, application of a control setting to down-regulate the prime-target congruence effect in response to target-response non-correspondence requires awareness of prime-target congruence in subsequent trials, conflict control could again be lower in unaware than aware conditions. This should be reflected in a reduced congruence effect in visible and non-corresponding conditions relative to visible and corresponding conditions but similar congruence effects in masked non-corresponding and masked corresponding conditions.

Experiment 1

We used (sandwich-masked) words denoting spatial positions (or directions) on the vertical axis (e.g., the word “up”) as more or less visible primes and as visible targets (cf. Ansorge et al., 2010). Words were used as stimuli for two reasons. Like simple geometrical shapes, such as arrows, words lead to prime-target congruence effects (e.g., Martens & Kiefer, 2010) and to motor activation (e.g., Proctor & Vu, 2002), regardless of their visibility (cf. Kinoshita & Hunt, 2008). In contrast to geometrical shapes, however, words are convenient as masked primes: With words, it is relatively easy (in comparison to masked shapes) to create a large set of different masked primes because virtually any prime word can be rendered invisible if presented with a sandwich mask (Kiefer & Brendel, 2006). Our mask consisted of a few letters that preceded the prime word at prime word position and a few letters that followed the prime word at prime word position. For half of Experiment 1’s participants, a sandwich mask diminished prime word visibility. For the other half of the participants, the prime words were better visible because no letter masks were used.

Importantly, the prime duration and the prime-target interval were the same in masked conditions and in unmasked conditions without a mask. The visible targets were either congruent or incongruent to the prime words, and required a quick response depending on their spatial meaning. If conflict control requires the participants’ awareness of the visual stimulus eliciting the conflict, we expected a higher amount of conflict regulation in unmasked than masked conditions.

We also asked our participants to give a judgment about the perceived prime-target relation in each trial. This was done after the quick response to the target and at leisure. For this task, a visual prompt was shown on the screen indicating the two buttons to be pressed for whether the actual trial contained a congruent or an incongruent prime-target sequence. In this manner, we assessed whether or not the prime was seen. Note also that we thus used the maximally sensitive task for the present purpose: Only judgments about the congruence or incongruence of the actual prime-target sequence will tap unambiguously into those visual representations that are responsible for the elicitation of conflict control.

We expected better performance in unmasked than masked conditions in this prime visibility test. More importantly, with this procedure, we were also able to restrict our analysis of conflict control of the target responses to only those trials in which the participants correctly judged the primes (here: the prime-target relation). Basing our conclusions about conflict control on only those trials that followed the trials in which our participants correctly judged the primes, we do not only assume but test whether the correct judgments in the masked conditions reflected unawareness of the primes (i.e., chance performance), too.

If the correct judgments in masked trials reflected chance performance and the participants, thus, remained unaware of the prime during these trials, and if conflict control requires awareness of the conflict-eliciting stimulus, Gratton effects or conflict control should be absent in the masked conditions, even if the Gratton effect is estimated solely on the basis of those trials that followed a trial in which participants correctly judged prime-target sequences in the masked condition.

In addition, we also varied the spatial correspondence between the spatial long-term meaning of the words and the required target responses. The target words required a spatially corresponding response in one block and a spatially non-corresponding response in the other block. In the corresponding block, an up target required an upwardly directed key press, and a down target required a downwardly directed key press. In the non-corresponding block, the target-response mapping was reversed: An up target required a downwardly directed key press, and a down target required an upwardly directed key press. In this manner, we tested whether conflict elicited in one domain (non-correspondence between target and response) led to conflict control in a second domain (prime-target congruence) and whether this kind of domain general conflict control was elicited in aware and unaware conditions.

Method

Participants. Forty-eight participants (18 female), mostly students, with a mean age of 25 years participated in exchange for money or course credit. All participants reported normal or corrected-to-normal visual acuity.

Apparatus. Visual stimuli were presented on a 15-inch, color VGA monitor. Its refresh rate was 59.1 Hz. The participants sat at a distance of 57 cm from the screen in a quiet, dimly lit room, with their head resting in a chin rest to ensure a constant viewing distance and a straight-ahead gaze direction. RTs were registered via the numeric keypad of a serial computer keyboard, placed directly in front of the observers. To start a trial, participants pressed the central key (#5) as a home key with the right index finger. They had to release the home key immediately before their target response. Target responses were given by the keys #2 and #8 (labeled “below” and “above”). After reading the instructions, participants started the experiment by pressing the key #8 once, and continued with the next trial by pressing the key #5.

Stimuli and procedure. See also Figure 1. Prime and target stimuli were German words denoting spatial positions on the vertical axis. The masked prime and the visible target words could either be ‘oben’ (on top), ‘darueber’ (above), ‘hinauf’ (upward), ‘hoch’ (high), ‘unten’ (down), ‘darunter’ (below), ‘hinab’ (downward), and ‘tief’ (deep). Each of the eight words was presented as a target and combined with each of the seven remaining words as a prime. Thus, a set of 56 (8×7) different prime-target pairs served as stimuli. Prime-target pairs were equally likely congruent or incongruent. In congruent conditions prime and target were of spatially related meaning (e.g., the prime word ‘high’ preceded the target word ‘above’) and in incongruent conditions prime and target had spatially opposite meaning (e.g., the prime word ‘below’ preceded the target word ‘on top’). Even in congruent conditions, prime and target were never identical to rule out repetition priming (Forster, 1998; Norris & Kinoshita, 2008).

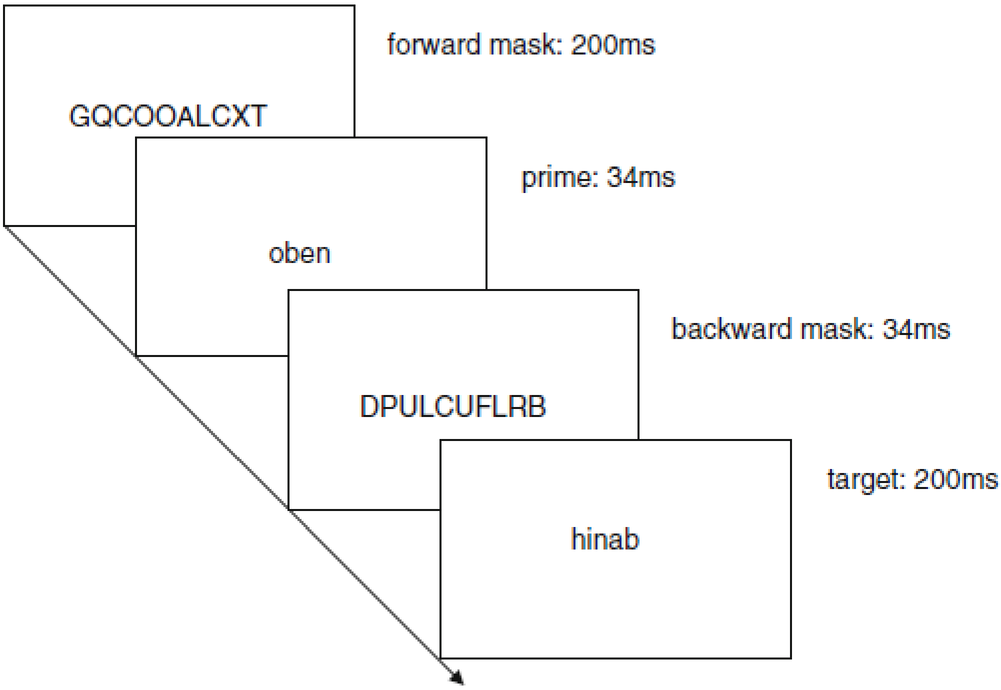

Figure 1: Depicted is an example of an incongruent trial. The arrow depicts the direction of time. Stimuli are not drawn to scale.

All stimuli were presented black (< 1 cd/m^2) on a gray background (24 cd/m^2). Each trial started with the presentation of a fixation cross centered on the screen for 750 ms. In the masked condition, a forward mask consisting of 10 randomly drawn uppercase letters was shown for 200 ms. Immediately after the forward mask, the prime word was shown for 34 ms (equivalent to two screen refreshes at 59.1 Hz) in lowercase letters. It preceded a backward mask also consisting of 10 independently drawn random capital letters which were shown for 34 ms. Next, the target word stimulus was shown and remained on the screen until the participant pressed one of the response keys. All stimuli were shown centred on the screen with inter-stimulus intervals (ISIs) of 0 ms. Timing of all stimuli was adapted from a prior study showing low prime visibility (cf. Kiefer & Brendel, 2006). In the unmasked condition, everything was the same with the exception of the masks that were not shown. Masking was realized as a between-participants variable.

The experiment was divided into two blocks, a block with corresponding target-response mapping and a block with non-corresponding target-response mapping target. Each block lasted about 45 min. During the corresponding block, participants gave spatially corresponding responses to the meaning of the visible target word. They pressed the upper key for target words denoting elevated positions or directions toward such positions. They pressed the lower key for target words denoting lower positions or directions toward such positions. During the non-corresponding block, participants gave spatially non-corresponding responses to the meaning of the visible target word. They pressed the upper key for target words denoting lower positions or directions toward lower positions, and they pressed the lower key for target words denoting elevated positions or directions toward elevated positions. The second task was a prime visibility task. In each trial, after the quick response to the target had been given, a second display showed up asking participants to judge whether they had seen a congruent or an incongruent prime-target pair. The stimulus-response mapping for this task changed from trial to trial on a random basis. This was done to prevent action triggering of the correct responses even if the stimuli were perfectly masked (cf. Kunde, Kiesel, & Hoffmann, 2003) and to secure that responses to the prime-target relation had to be based on the participants' awareness about the prime-target relation (cf. Reingold & Merikle, 1989).

Regarding the target responses, after each trial, participants received feedback in case of errors (“Wrong key!”) and if their RT exceeded 1,250 ms (“Respond faster!”). Feedback took 750 ms. Thus, keeping a high accuracy and a fast response speed for the targets was mildly rewarded (i.e., saved time). No feedback was given concerning the prime visibility task.

Each block consisted of 320 trials. This corresponds to eighty repetitions of each of the 2 target types (upward targets; downward targets) × 2 prime types (upward primes; downward primes), with each of the 8 targets being equally frequent and prime words being randomly chosen from the set of available prime words for each particular combination of the two possible spatial target meanings and the two possible congruence levels. Within blocks, different conditions were realized in a pseudo-random order. Prior to each block, participants practiced the task for 32 trials.

Results and Discussion

Data from one participant per each group were excluded, leaving 23 participants in each group. These participants had a large rate of congruence judgments of one particular type (> 95%), meaning that it was uncertain whether they understood the task at all. Out of all responses, 4.0% were discarded because correct individual RTs deviated by more than 2 standard deviations (SDs) from individual mean RTs, or because only one response was given. Degrees of freedom were adjusted by Greenhouse Geisser ε if Mauchly sphericity tests indicated that the assumption of independent variance across steps of the variables was violated.

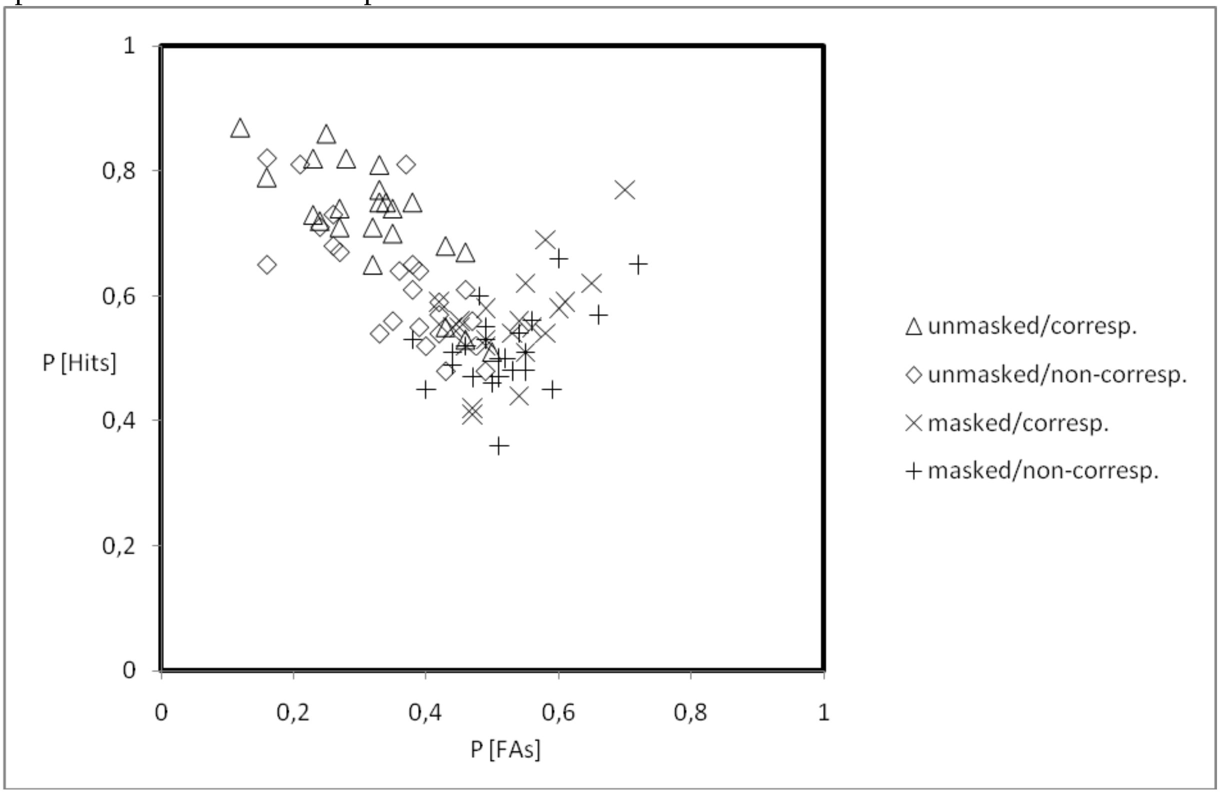

Figure 2: Depicted are individual hit rates (on the x axis) as a function of individual false alarm (FA) rates (on the y axis), target-response correspondence (corresp. = corresponding vs. non-corresp. = non-corresponding), and masking (masked vs. unmasked). As can be seen, the data from the masked condition roughly align with the diagonal through the origin of the coordinate system. This diagonal corresponds to equal rates of hits and FAs, that is, chance performance. By contrast, in the unmasked condition, hit rates outweigh FA rates. Likewise, hit-to-FA ratios are higher for corresponding than non-corresponding conditions. Data from Experiment 1.

Prime visibility/prime-target judgments. See Figure 2 for the results. Visibility of the primes was assessed by prime-target judgments. To assess prime visibility, *d’* indices of signal detection theory (Green & Swets, 1966; Macmillan & Creelman, 2005) were calculated based on congruent conditions as signals, and incongruent conditions as noise, so that a ‘congruent’ judgment in the congruent (signal) condition counted as a hit and a ‘congruent’ judgment in the incongruent (noise) condition counted as a false alarm (FA). Next, the rates of hits and FAs were individually *z*-transformed and individual *d’* was calculated as the difference between the *z*-transformed hit rate minus the *z*-transformed FA rate. Finally, *d’* was averaged across participants and compared to zero by *t* tests, because an average *d’* of zero corresponds to chance performance, and *d’* can become ever larger the better the discrimination of the participants. In the unmasked conditions, primes were visible. *d*’ amounted to a significant 1.10, $t(22) = 9.94$, $p < .01$, in the target-response corresponding block, and to 0.74, $t(22) = 6.94$, $p < .01$, in the target-response non-corresponding block. In the masked conditions, primes were invisible. *d*’ amounted to a non-significant 0.07, $t(22) = 1.76$, $p = .09$, in the target-response corresponding block, and to -0.008, $t(22) < 1.00$, in the target-response non-corresponding block.

A two-way ANOVA of the mean *d’* indices with the within-participant variable target-response correspondence (target-response corresponding vs. target-response non-corresponding) and the between-participants variable masking (masked primes vs. unmasked primes) led to significant main effects of both variables, masking, $F(1, 44) = 12.61$, $p < .01$, and target-response compatibility, $F(1, 44) = 80.28$, $p < .01$, and a significant two-way interaction between these variables, $F(1, 44) = 5.46$, $p < .05$.

The main effects reflected that judgments were better in unmasked than masked conditions, and in target-response corresponding than in target-response non-corresponding conditions, and a significant two-way interaction demonstrated that this drop of performance from corresponding to non-corresponding blocks was more dramatic in the unmasked blocks than in the masked blocks.

Generally, the performance drop in the target-response non-corresponding blocks relative to the target-response corresponding blocks made it clear that the suspicion of other researchers was right (e.g., Klotz & Neumann, 1999) that testing prime visibility and prime congruence effects in the same trials is not the most sensitive procedure for revealing residual prime visibility because this is essentially a dual-task situation in which the demands imposed by the target-response task interferes with optimal performance in the prime visibility task. The likely reason for the two-way interaction was that there was not much to see in the masked blocks in the first place. Therefore, the dual-task interference with the visibility measure could not have been as strong in the masked blocks as it had been in the unmasked blocks.

Target RTs. See also Table 1 for the results. A repeated-measures ANOVA was run based on only those trials in which participants correctly responded to the visible targets within the RT limits (of +/- 2 SDs of the individual mean correct RTs) in the just preceding and current trial and in which they correctly judged prime-target congruence relations in the just preceding trial. This ANOVA concerned the medians of the correct responses, with the within-participant variables preceding prime-target congruence in trial *n-1* (preceding congruent; preceding incongruent), current prime-target congruence in trial *n* (congruent; incongruent), and target-response correspondence (corresponding; non-corresponding), and the between-participants variable masking (yes; no).

This ANOVA led to significant main effects of current congruence, $F(1, 44) = 26.97$, $p < .01$, and correspondence, $F(1, 44) = 115.05$, $p < .01$. Responses were faster in current congruent (RT = 746 ms) than in current incongruent trials (RT = 768 ms), and in corresponding (RT = 699 ms) than in non-corresponding conditions (RT = 815 ms). In addition, we found the expected significant three-way interaction of Current Congruence × Preceding Congruence × Masking, $F(1, 44) = 3.90$, $p = .05$, plus a significant three-way interaction of Correspondence × Current Congruence × Masking interaction, $F(1, 44) = 4.24$, $p < .05$.

The first three-way interaction reflected the predicted conflict control only in the visible (unmasked) conditions but not in the invisible (masked) conditions. We found a significant drop of the current trial’s congruence effect (incongruent RT – congruent RT) in the visible conditions by 18 ms down from 33 ms after a preceding congruent trial to 15 ms after a preceding incongruent trial, $t(22) = 2.48$, $p < .05$, and the absence of such a drop in the masked conditions in which current congruence effects after a preceding congruent trial (18 ms) and a preceding incongruent trial (20 ms) did not significantly differ from one another, $t < 1.00$. The second three-way interaction was caused by a significant drop of 26 ms, $t(22) = 2.46$, $p < .05$, of the current congruence effect in the visible conditions for blocks in which participants responded non-correspondingly (congruence effect: 11 ms) as compared to blocks that required a corresponding response (congruence effect: 37 ms). This drop was absent in the invisible (masked) conditions in which the current congruence effect was 18 ms in corresponding blocks and, thus, about the same as the 20 ms in non-corresponding blocks.[1]

Additional RT analyses. We ran two additional analyses of only the masked conditions that were not justified by significant interactions in the omnibus ANOVA but interesting nonetheless. The first additional ANOVA was conducted because van Gaal et al. (2010) reported residual conflict control in the masked conditions. These authors used only corresponding target responses. Therefore, we also tested whether in the corresponding blocks the small drop by 5 ms of the masked primes' congruence effect after preceding incongruent trials (congruence effect: 15 ms) as compared to preceding congruent trials (congruence effect: 20 ms) was reliable. However, in a repeated measures ANOVA of only the masked and corresponding conditions, with the two variables preceding congruence and actual congruence the interaction failed to become significant, $F < 1.00$, too.

Table 1. Reaction times, error rates, and congruence effects (incongruent – congruent) in Experiment 1.

unmasked condition

		pre. con.			pre. inc.		
		con.	inc.	effect	con.	inc.	effect
corr.	RT	679	724	45	694	723	29
	ER	*1.7*	*2.7*	*1.0*	*2.4*	*4.4*	*2.0*
non-cor.	RT	807	828	21	817	818	1
	ER	*1.7*	*4.2*	*2.5*	*1.2*	*2.4*	*1.2*

masked condition

		pre. con.			pre. inc.		
		con.	inc.	effect	con.	inc.	effect
corr.	RT	682	703	21	687	702	15
	ER	*2.7*	*4.1*	*1.4*	*2.1*	*4.0*	*1.9*
non-cor.	RT	803	818	15	803	828	25
	ER	*2.5*	*3.0*	*0.5*	*2.7*	*3.6*	*0.9*

Table note. RT = Reaction Time (in ms); ER = Error Rate (in %); corr. = corresponding; non-cor. = non-corresponding; pre. con. = preceding congruent; pre. inc. = preceding incongruent; con. = congruent; inc. = incongruent

A second additional ANOVA was conducted to test whether the "reverse conflict control effect" in the non-corresponding masked conditions with a higher congruence effect after preceding incongruent (congruence effect = 25ms) than preceding congruent conditions (congruence effect = 15 ms) was significant. This repeated measures ANOVA only concerned the masked and non-corresponding trials and was also run with preceding congruence and actual congruence as its variables but again the interaction was not significant, $F < 1.00$.

Errors. A corresponding ANOVA of the arc-sine transformed error rates (ERs) led to a significant main effect of current congruence, $F(1, 44) = 16.58$, $p < .01$, and to a significant three-way interaction of Correspondence × Preceding Congruence × Masking, $F(1, 44) = 5.61$, $p < .05$. The current congruence effect reflected better performance in congruent (ER = 2.1%) than incongruent conditions (ER = 3.5%). The three-way interaction reflected an almost significant reversal of the congruence effect in the preceding trial (preceding congruent RT – preceding incongruent RT) during visible blocks in non-corresponding conditions (0.6%) relative to corresponding conditions (-1.6%), $t(22) = -1.96$, $p = .06$, but if anything a reversal of this pattern in the masked conditions in which the preceding trial's congruence effect was a little stronger for corresponding (0.4%) and non-corresponding blocks (-1.4%), $t(22) = 1.46$, $p = .16$.

Discussion

Experiment 1 nicely confirmed that conflict control was only elicited by visible primes and not by masked primes. Because participants were unaware of the masked primes as demonstrated by chance performance in the discrimination of the present prime-target relations, this observation supported the notion that conflict control is conditional on aware perception of the conflict-eliciting stimulus. Moreover, several alternative explanations that could have accounted for prior instances of reduced conflict control under unawareness conditions were ruled out. Echoing Kunde's (2003) results, we found that conflict control was selectively possible with visible primes but not with masked primes, but this time and in contrast to Kunde (2003), conditions with better visible primes and with masked and with visible primes were exactly matched for the length of the prime-target interval. Thus, an alternative explanation of the difference between aware and unaware priming conditions in terms of prime-target intervals (cf. Vorberg, 2009) was ruled out. Also, the amount of response conflict, as expressed in terms of the size of the congruence effect, was quite comparable in conditions with masking (19 ms) and without masking (24 ms). So differences of conflict that sometimes occur when prime awareness is manipulated are unlikely to explain why conflict adaptation occurred when primes were visible but did not occur when the primes were invisible.

We also found that conflict control was selectively possible with visible primes but not with masked or invisible primes, although the results were based on only correctly judged prime-target sequences in both, visible and masked conditions. This rules out that the participants' beliefs (rather than what they actually saw) governs the Gratton effect and could have falsely suggested the absence of a Gratton effect in prior masked priming experiments.

This observation also suggests that the Gratton effect cannot be based on the mere intention to somehow reduce interference. Apparently, it does not suffice to believe that a conflicting event had just occurred; instead, this conflicting event must also have left a conscious trace to govern conflict adaptation. However, with masking the prime visibility, the task was difficult and it might be that participants were more or less guessing. So a correct judgment of prime-target congruence need not necessarily reflect much confidence of the observer about this judgment. Therefore future research seems necessary to clarify to which extent conflict control can be achieved strategically without previous occurrence of conflict.

The conclusion that conflict control was only possible in visible but not in invisible priming conditions was additionally supported by our observation of a second kind of selective conflict control in the visible priming conditions. In prior masked priming studies it had been found that a current trial's congruence effect was larger after a preceding congruent trial than after a preceding incongruent trial, only with visible primes (Greenwald et al., 1996; Kunde, 2003; van Gaal et al., 2010). In the current study, we additionally found that conflict in an alternative dimension elicited control of the prime-target congruence effect only in visible but not in masked conditions, too. This domain-general conflict-elicited control was based on a non-correspondence between the spatial long-term meaning of a clearly visible target word and the required response. This non-correspondence elicited conflict and led to control of conflict based on the visible primes' incongruence with the targets, too. In line with the assumption that word-response non-correspondence elicited conflict, we found a large significant correspondence effect, with slower responses in non-corresponding than corresponding blocks (cf. Lu & Proctor, 1995). In line with an awareness-dependent and domain-general elicitation of conflict control (cf. Botvinick et al., 2004), we also found only in conditions with a visible prime but not in conditions with an invisible (masked) prime, that conflict induced by word-response non-correspondence reduced the prime-target congruence effect of a visible prime as compared to the prime-target congruence effect in word-response corresponding condition. No such elicitation of across-domain conflict control of prime-target congruence effects by word-response non-correspondence was found with invisible primes. This result suggests that the application of conflict control elicited in prior trials to a new domain also required awareness.

However, the present finding that masked primes failed to elicit any conflict control is at odds with recent observations by van Gaal et al. (2010). These authors found a weak but significant residual diminution of the congruence effect by 9 ms in masked conditions, if the preceding trial was incongruent in comparison to a preceding trial with a congruent prime-target sequence. It is possible that the slightly weaker overall congruence effect of the masked word primes in the present study as compared to the stronger overall congruence effect of the masked shape primes in van Gaal et al.'s study was insufficient to elicit significant residual conflict control here. Another difference to the study by van Gaal et al. (2010) relates to our use of a warning signal (fixation cross) before presentation of the imperative stimuli, and a relatively long inter-trial interval (due to interspersing the judgment task). It might be that weak conflict adaptation effects from masked primes die out more likely with a long inter-trial interval and if a signal tells subjects that a new trial starts. At any rate, the main conclusion of Experiment is barely qualified by this fact because conflict-elicited control was virtually completely dependent on visual awareness here and in van Gaal et al.'s study, and prime-target intervals or different fractions of correct judgments in the preceding trial cannot better account for the difference between visible and invisible priming conditions.

We also observed an unexpected three-way interaction between a preceding trial's congruence effect, word-response correspondence, and visibility. We have no idea what the origin of this three-way interaction might be. We suggest waiting with an explanation until this interaction has been replicated in future experiments.

Experiment 2

The first experiment had a few shortcomings that we wanted to overcome in the second experiment. First, in Experiment 1, our participants had two tasks per each trial. They had to quickly respond to the target and then to judge whether the prime-target sequence was congruent or incongruent at their leisure. This, however, is not optimal because we thereby probably underestimated both effects: prime-target conflict effects (and conflict-elicited control of these effects), as well as prime visibility.

Therefore, in Experiment 2, we skipped the task of quickly responding to the visible targets and only used the prime visibility test. We simply studied the prime-target congruence effect and its control in the judgment times of the prime-target congruence judgments.

Second, in Experiment 1, our conclusion was based on a between-participants variable of masking. It is desirable to realize both conditions, visible and masked priming conditions within participants to rule out that different degrees of conflict control could have reflected (chance) differences between participants. To run both conditions within the same participants we used two blocks per participant, one with masked and one with visible primes and asked for only the prime-target judgment, and skipped manipulation of the variable word-response correspondence. In all other respects the experiment was exactly the same as Experiment 1.

Method

Participants. Twenty-five participants (16 female), mostly students, with a mean age

of 24 years participated in exchange for money or course credit. All participants reported normal or corrected-to-normal visual acuity.

Apparatus, stimuli, and procedure. These were the same, except for the following changes. In each trial, participants only had to judge whether the actual trial contained a congruent or an incongruent prime-target sequence. Half of the participants gave an upward response for a congruent trial and a downward response for an incongruent trial, while this mapping rule was reversed for the other half of the participants. All participants received masked and unmasked priming conditions in different blocks, with block order (masked first; unmasked first) balanced across participants.

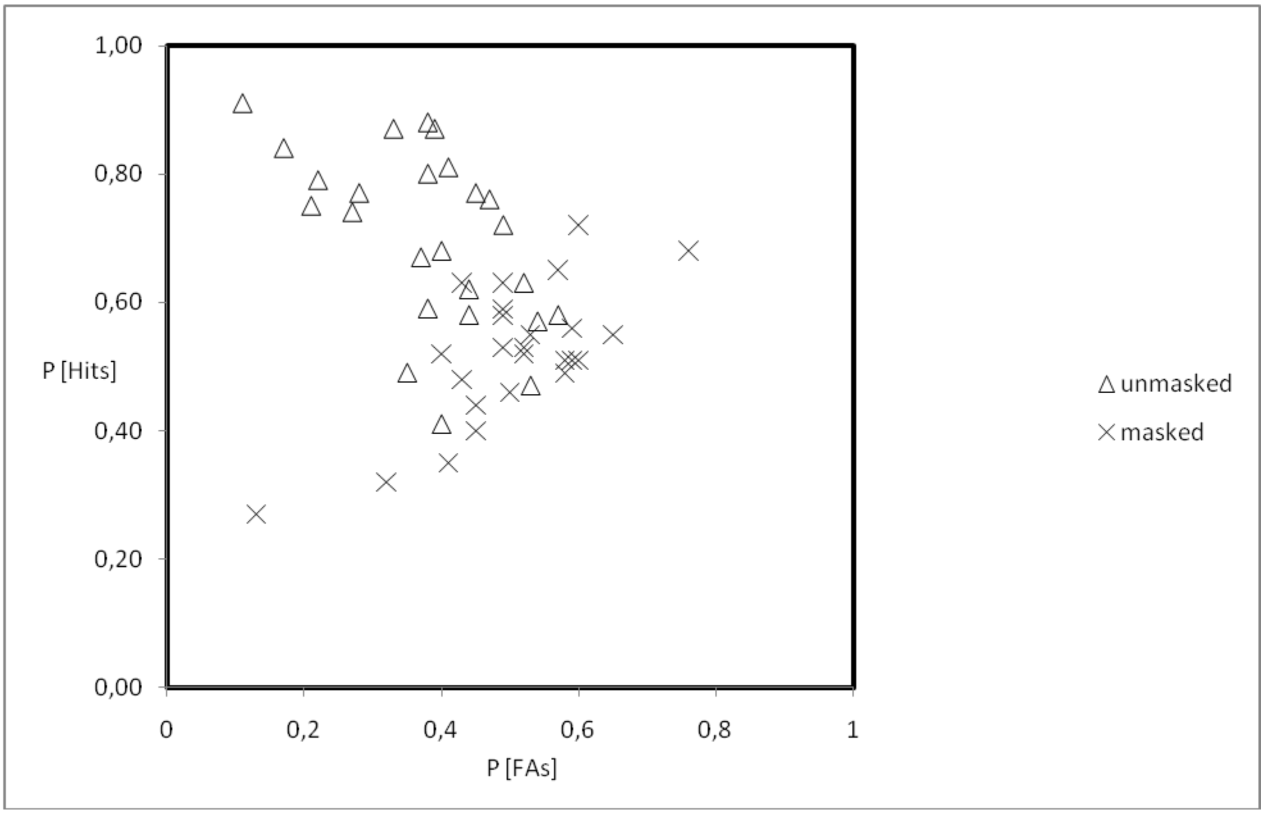

Figure 3: Depicted are individual hit rates (on the x axis) as a function of individual false alarm (FA) rates (on the y axis) and masking (masked vs. unmasked). As can be seen, the data from the masked condition roughly align with the diagonal through the origin of the coordinate system. This diagonal corresponds to equal rates of hits and FAs, that is, chance performance. By contrast, in the unmasked condition, hit rates outweigh FA rates. Likewise, hit-to-FA ratios are higher for corresponding than non-corresponding conditions. Data from Experiment 2.

Results

Prime visibility/prime-target judgments. See Figure 3 for the results. In the unmasked conditions, primes were visible. *d*’ amounted to a significant 0.82, $t(24) = 7.19$, $p < .01$. In the masked conditions, primes were invisible. *d*' amounted to a non-significant 0.05, $t(24) = 1.00$, $p = .16$. *d'* in unmasked conditions was also significantly higher than in masked conditions, $t(24) = 6.42$, $p < .01$.

Judgment Times. See also Table 2 for the results. Out of all trials, 4.6% were excluded because RTs differed by more than two standard deviations from individual mean RTs. A repeated-measures ANOVA of the medians of the judgment times was run with only those trials in which participants correctly judged congruence relations in the just preceding trial. This ANOVA had three within-participant variables, preceding prime-target congruence in trial *n-1* (preceding congruent; preceding incongruent), current prime-target congruence (congruent vs. incongruent), and masking (yes vs. no).

Table 2. Reaction times, error rates, and congruence effects (incongruent – congruent) in Experiment 2.

unmasked condition

	pre. con.			pre. inc.		
	con.	inc.	effect	con.	inc.	effect
RT	1,301	1,385	84	1,428	1,426	-12
ER	*30.6*	*34.0*	*3.4*	*28.8*	*42.9*	*14.1*

masked condition

	pre. con.			pre. inc.		
	con.	inc.	effect	con.	inc.	effect
RT	881	893	12	894	916	22
ER	*54.4*	*45.9*	*-8.5*	*42.2*	*55.7*	*13.5*

Table note. RT = Reaction Time (in ms); ER = Error Rate (in %); pre. con. = preceding congruent; pre. inc. = preceding incongruent; con. = congruent; inc. = incongruent

This ANOVA led to significant main effects of masking, $F(1, 14) = 24.21$, $p < .01$, and preceding congruence, $F(1, 24) = 8.18$, $p < .01$. Responses were faster in masked (RT = 896 ms) than unmasked (RT = 1,383 ms) conditions and after a preceding congruent trial (RT = 1,115 ms) than after a preceding incongruent (RT = 1,164 ms) trial. Most importantly, there was a significant three-way interaction of Masking × Preceding Congruence × Current Congruence, $F(1, 24) = 5.02$, $p < .05$, that reflected a current congruence effect, with faster responses in current congruent (RT = 1,301 ms) than incongruent (RT = 1,385 ms) trials, only for visible prime trials that followed a preceding congruent trial, $t(24) = 2.33$, $p < .05$. The current trial's congruence effect was absent after a preceding visible incongruent trial (current congruent RT = 1,428 ms; current incongruent RT = 1,416 ms, $t < 1.00$), and in the masked conditions, after a preceding congruent trial (current congruent RT = 881 ms; current incongruent RT = 893 ms; $t < 1.00$) and after a preceding incongruent trial (current congruent RT = 894 ms; current incongruent RT = 916 ms; $t[24] = 1.02$, $p = .31$).

In addition, we observed trends towards significant main effects of current congruence, $F(1, 24) = 3.11$, $p = .09$, and towards a significant two-way interaction of Preceding Congruence ×

Masking, $F(1, 24) = 3.44$, $p = .08$. The trend towards current congruence mirrored the typical better performance in current congruent (RT = 1,126 ms) than current incongruent (RT = 1,153 ms) conditions. The two-way interaction reflected that a larger cost was incurred by a visible preceding incongruent (RT = 1,422 ms) than a preceding congruent (RT = 1,343 ms) trial than by a preceding masked incongruent (RT = 905 ms) as compared to a preceding masked congruent (RT = 887 ms) trial.

A corresponding ANOVA of the arc-sine transformed ERs led to a significant main effect of masking, $F(1, 24) = 64.07$, $p < .01$, and to significant two-way interactions of Masking × Preceding Congruence, $F(1, 24) = 7.17$, $p < .05$, and of Preceding Congruence × Current Congruence, $F(1, 24) = 7.02$, $p < .05$. The main effect of masking was trivial and reflected a higher percentage of errors in masked (ER = 49.6%) than in unmasked (ER = 34.1%) conditions. The two-way interaction of masking and preceding congruence reflected an almost significant selective cost incurred by a visible preceding incongruent (ER = 35.8%) as compared to a visible preceding congruent (ER = 32.3%) condition in visible trials, $t(24) = 1.90$, $p = .07$, that was numerically reversed in masked conditions (preceding congruent ER = 50.1%; preceding incongruent ER = 49.0%; $t[24] < 1.00$). The two-way interaction of preceding congruence and current congruence was due to a selective congruence effect after preceding incongruent conditions (current congruent ER = 35.5%; current incongruent ER = 49.3%; $t[24] = 3.47$, $p < .01$) that was absent after preceding congruent conditions (current congruent ER = 42.5%; current incongruent ER = 40.0%; $t < .100$). The three-way interaction was not significant, $F(1, 24) = 2.47$, $p = .13$: Current congruence effects (incongruent ER – congruent ER) were observed after both masked (current congruence effect = 13.5%) and visible preceding incongruent (current congruence effect = 14.0%) trials, both ts(24) > 2.27, both ps < .05. In the ANOVA of the ERs, the main effect of preceding congruence, $F < 1.00$, and the two-way interaction, $F(1, 24) = 1.74$, $p = .20$, were not significant.

Discussion

In Experiment 2, we confirmed the exclusive presence of conflict control in the aware conditions, with visible priming trials. With visible primes, the Gratton effect was weak though. It was only present in the judgment times. In the ERs, by contrast, for the visible and for the masked primes, there was a stronger congruence effect after preceding incongruent trials. However, the difference between the Gratton effects in RTs under aware and unaware priming conditions made it quite clear that selective conflict control in aware conditions but absence of conflict control in unaware conditions persisted. Not even the weak RT evidence for a Gratton effect that we observed in aware or visible conditions was found in the unaware or masked conditions. This difference in conflict control was found with masked and visible priming conditions realized within the same participants.

We also observed a significant main effect of masking on RTs and (obviously and trivially) on ERs. Concerning the ER effect, because we asked our participants to judge prime-target congruence relations and because primes were barely visible in the masked condition, the ER in the masked condition had to be higher than in the visible condition. This is in contrast to the results of Experiment 1 because in Experiment 1 the corresponding ER effects were not measured as prime-target congruence influences on judgment times but (as in standard masked priming experiments) as prime-target congruence influences on RTs to clearly visible targets.

By comparison to the ER effect, the effect of the variable masking on judgment times is more interesting. Faster judgments in masked than unmasked conditions indicated that participants took less time for their judgments of prime-target relations in masked than in unmasked conditions. Thus, it is possible that part of the lower rate of correct judgments in the masked condition as compared to the unmasked condition reflected a speed-accuracy trade-off. On a more fundamental level, however, one has to ask for the probable reason of this ER effect. We think that it is plausible that participants simply took little time for judging of masked prime-target relations because this was impossible – that is, the masked primes were hardly seen.

One final aspect of Experiment 2 is noteworthy. The fact that a congruence effect was observed at all suggested that this congruence effect reflected a kind of semantic interference between the prime and target meaning in incongruent trials (cf. Kiefer & Spitzer, 2001). This is so because, there was no response conflict between prime and mask in the congruent condition, nor in the incongruent condition, because all congruent prime-target relations required one and the same response, and all incongruent prime-target relations required one and the same alternative response. Therefore, a response could not be activated on the basis of the prime alone, and hence there was no prime-target response conflict in any of the conditions.

General Discussion

In the present study, we ran two experiments to test the hypothesis that awareness about (here: the visibility of) a conflict-eliciting stimulus is necessary for subsequent conflict control (Kunde, 2003). We confirmed this hypothesis and found that conflict control depended on the participants' awareness about the conflict-eliciting stimulus.

In Experiment 1, we wanted to rule out that the time for the processing of a conflict-eliciting stimulus – a variable fully confounded with the participants' awareness of a conflict-eliciting stimulus (or its visibility) in prior experiments (cf. Greenwald et al., 1996; Kunde, 2003; van Gaal et al., 2010) – provided a better explanation for lower degrees of conflict control in masked than unmasked conditions. We therefore kept the time for the processing of the conflict-eliciting stimulus exactly the same in aware (visible) and unaware (invisible) priming conditions. Yet, conflict control was only elicited by the visible stimulus of which participants were aware (Experiments 1 and 2). In addition, in line with a domain-general conflict control principle (cf. Botvinick et al., 2004), we found that a visible stimulus that elicited conflict in one domain (here: stimulus-response conflict) also triggered conflict control in an alternative domain (here: stimulus-response congruence), but again only if participants were aware of the primes – that is, in visible priming conditions. Again, the same kind of conflict failed to trigger conflict control if participants were unaware of the primes because the primes were masked and thus invisible. Evidently nothing prevented conflict by target-response non-correspondence, even in the masked priming conditions because this conflict depended on the fit between the visible target's spatial long-term meaning and the response directions, and because the participants were thus aware of the conflict-eliciting stimulus even in the masked priming conditions. This was confirmed by a large RT cost that was incurred in non-corresponding relative to corresponding conditions, in both masked and unmasked priming conditions. The failure of domain-general conflict control in the masked priming conditions therefore indicated that the application of a control setting to down regulate the prime processing as a consequence of conflict in another domain also required that the participants were aware of the stimulus to which the control setting was to be applied.

Another aspect that we criticized in prior research on the control of conflict with unaware stimuli concerned the implications of the low measured visibility of the conflict-eliciting stimulus for the correct interpretation in this research. In former research, authors used about equal numbers of incorrectly and correctly judged visual conflict-eliciting stimuli in a preceding trial for a test of conflict control in unaware conditions (e.g., Kunde, 2003). However, in the aware conditions of the same studies, the number of correctly judged visual conflict-eliciting stimuli by far exceeded the number of incorrectly judged visual stimuli. Therefore, former studies of awareness and conflict control based their comparison of conflict control under aware vs. unaware conditions on unequal numbers of correctly judged stimuli in aware vs. unaware conditions. If the correct judgment about a visual stimulus reflected the participants' belief in whether they saw a conflicting stimulus and if the participants' belief about whether they saw a conflicting stimulus was necessary for conflict-elicited control, then it is no wonder that basing conclusions on a larger number of incorrectly judged stimuli in unaware conditions, researchers (e.g., Greenwald et al., 1996; Kunde, 2003) found less evidence for conflict control if participants more often believed that factually conflict-eliciting stimuli were not conflicting and that factually non-conflicting stimuli were conflicting.

In the present study, however, this was not a concern because we asked our participants to judge the conflict-eliciting stimulus in each and every trial. As a consequence, we were able to base even our analysis of conflict control in unaware conditions, solely on those trials, which followed a correctly judged conflicting stimulus. Although this is a very conservative measure, we still found the expected difference in conflict control between aware and unaware conditions: No conflict control in the unaware condition at all, but conflict control in the aware condition. The reason for this finding is probably that even the correct judgments in the unaware condition reflected chance performance, an assumption that so far was rarely tested but was confirmed by implication of the present study's results.

One caveat of the conclusions from the present Experiment 1, however, was that we collected the data in a dual-task condition, with one quick response for the measurement of conflict and conflict control and one slower judgment about the visual stimulus for the test of awareness of the conflict-eliciting stimulus. This dual-task procedure must have led to an underestimation of the participants' awareness for the conflict-eliciting stimuli, as well as to an underestimation of conflict and conflict control. To overcome this problem, we switched to a simpler judgment-only task in Experiment 2 – that is, we skipped the quick responses to the visible targets. Instead, we tested the conditions for conflict control by way of the judgment times. The judgment times had a much larger variance than the quick target responses in Experiment 1. Therefore, overall conflict effects were weak in Experiment 2 and so was conflict control. This shortcoming notwithstanding, we were able to again confirm selective conflict control if participants were aware of the conflict-eliciting stimuli.

The current study thus confirmed that particular forms of top-down control, namely conflict control in response to visual conflict-eliciting stimuli (cf. Gratton et al., 1992), are dependent on the participants' awareness of the conflict-eliciting stimulus. This, however, does not mean that each form of top-down control requires awareness about the stimulus to be processed. Kunde, Kiesel and Hoffmann (2003), for example, showed that top-down control over the processing of a visual stimulus' meaning can be exerted even in the absence of the participants' awareness for the stimulus. There are numerous other instances in which top-down control was exerted even with stimuli remaining below the threshold of aware perception (cf. Ansorge & Neumann, 2005; Held, Ansorge, & Müller, in press; Schlaghecken & Eimer, 2004).

This brings us to a final question: What is the decisive difference between the situations in which top-down control can be exerted over the processing of stimuli of which observers remain unaware (cf. Ansorge, Horstmann, & Worschech, 2010; Ansorge, Kiss, & Eimer, 2009; Kiefer & Martens, 2010; Kunde et al., 2003; Lau & Passingham, 2007; Mattler, 2005), and the conditions in which top-down control fails because participants remain unaware of the stimuli (cf. Cheesman & Merikle, 1985; Greenwald et al., 1996; Held, Ansorge, & Müller, in press; Kunde, 2003; McCormick, 1997)? The difference seems to be whether or not a top-down control setting that fits to the subliminal stimuli can be set up in advance of the stimuli. If a top-down set is already in place, even a stimulus that is presented below the threshold of aware perception can be processed if it fits to the task set. For example, if participants know in advance that they need to press a key in response to a number below five, presenting a visual number four outside the participants' awareness, the number four will nonetheless activate its response (cf. Dehaene et al., 1998; Kunde et al., 2003).

One might wonder, how this could explain the lack of conflict control after target-elicited conflict in the non-corresponding conditions of the present Experiment 1's masked priming conditions. One possibility is that top-down control settings for conflict control were set up for the control of the responses to the visible targets in the non-corresponding blocks, but that these could not be applied to the masked primes because conflict elicited by the masked primes reflected interference between the semantic processing of incongruent primes and targets rather than response activation effects of the masked primes. In line with this, semantic conflict alone produced a prime-target congruence effect in Experiment 2 when response conflict was ruled out. According to this explanation the fact that different processes are involved in conflict in non-corresponding conditions vs. conflict in incongruent conditions (i.e., sensorimotor processes in the case of non-correspondence and semantic processes in the case of incongruence), means that the two types of conflict could in principle be solved by different forms of conflict control. Hence, conflict control to down-regulate motor activation by visible targets in non-corresponding blocks could be without consequence for the masked prime's semantic interference effect in incongruent conditions. This is so at least unless the participants' awareness of the primes suggested that control over the processing of the semantic meaning of the targets and the primes could be a way to take care of both sources of inference at one and the same time. In this respect, our results might not generalize to other forms of stimulus-elicited conflict control, like conflict control after incongruent geometrical shapes such as squares and diamonds (e.g., Neumann & Klotz, 1994), because these geometrical stimuli might not necessarily activate strong semantic representations and instead might only activate motor responses. Hence, it will be interesting to directly compare masked priming with words and with geometrical stimuli with respect to its vulnerability to domain-general conflict control in future studies.

To make the argument complete, however, on a more general note, we need to understand why conflict control as it was reflected in the Gratton effect cannot be applied to unaware stimuli. The crucial difference seems to be the fact that conflict control of the Gratton type requires changing rather than keeping the advance top-down settings. For the Gratton effect, top-down settings must be revised on the basis of recent evidence. This kind of control cannot be solved beforehand by a fix control setting. It seems to be much less likely that a top-down control setting is revised in response to the information delivered by a stimulus that remains outside the participants' awareness as suggested by results beyond the scope of the present research. For example, if a conflict-eliciting condition with a masked and therefore invisible word plus a visible target word (e.g., a girl's name as a prime preceding a boy's name as a target) is so probable in the context of an experiment that participants would be well advised to prepare for an alternative response (e.g., prepare pressing the key for boy's name when the prime is a girl's name) than the one that would be indicated by the invisible prime word (e.g., the key for a girl's name when the prime is a girl's name), participants fail to develop this alternative strategy if the incongruent word is also invisible (cf. Ansorge, Heumann, & Scharlau, 2002; Cheesman & Merikle, 1985; McCormick, 1997). It is exactly this kind of reactive and changing rather than advance and fix top-down control that would also be necessary to control the processing of the next visual stimulus after a conflict-eliciting visual stimulus in a just preceding trial. This sort of reactive control seems to require awareness about the stimulus, as has been confirmed in the present study, too, but further investigations are certainly desirable to confirm this conclusion and exactly map out the limits of reactive top-down control (cf. Jaśkowski, Skalska, & Verleger, 2003).

References

Alpern, M. (1953). Metacontrast. *Journal of the Optical Society of America*, *43*, 648-657.

Ansorge, U., Heumann, M., & Scharlau, I. (2002). Influences of visibility, intentions, and probability in a peripheral cuing task. *Consciousness and Cognition*, *11*, 528-545.

Ansorge, U., Horstmann, G., & Worschech, F. (2010). Attentional capture by masked color singletons. *Vision Research, 50*, 2015-2027.

Ansorge, U., Kiefer, M., Khalid, S., Grassl, S., & König, P. (2010). Testing the theory of embodied cognition with subliminal words. *Cognition*, *116*, 303-320.

Ansorge, U., Kiss, M., & Eimer, M. (2009). Goal-driven attentional capture by invisible colours: Evidence from event-related potentials. *Psychonomic Bulletin & Review*, *16*, 648-653.

Ansorge, U., & Neumann, O. (2005). Intentions determine the effect of invisible metacontrast-masked primes: Evidence for top-down contingencies in a peripheral cueing task.

Journal of Experimental Psychology: Human Perception and Performance, *31*, 762-777.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences*, *8*, 539-546.

Botvinick, M., Nystrom, L. E., Fisell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring vs. selection-for action in anterior cingulate cortex. *Nature, 402*, 179-181.

Breitmeyer, B. G., & Ogmen, H. (2006). *Visual masking: Time slices through conscious and unconscious vision*. Oxford, UK: Oxford University Press.

Carter, C. S., & van Veen, V. (2004). Anterior cingulate cortex and conflict detection: An update of theory and data. *Cognitive, Affective, & Behavioral Neuroscience*, *7*, 367-379.

Cheesman, J., & Merikle, P. M. (1985). Word recognition and consciousness. In D. Besner, T. G. Waller, & G. E. MacKinnon (Ed.), *Reading research: Advances in theory and practice* (pp. 311-352). New York, NY: Academic Press.

Davelaar, E. J., & Stevens, J. (2009). Sequential dependencies in the Eriksen flanker task: A direct comparison of two competing accounts. *Psychonomic Bulletin & Review*, *16*, 121-126.

Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P., & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature, 395*, 597-600.

Dehaene, S., Artiges, E., Naccache, L., Martelli, C., Viard, A., Schürhoff, F., Recasens, C., Paillère-Martinot, M.-L., Leboyer, M., & Jean-Luc Martinot (2003). Conscious and subliminal conflicts in normal subjects and patients with schizophrenia: The role of the anterior cingulate. *Proceedings of the National Academy of Sciences, USA*, *100*, 13722-13727.

De Jong, R., Liang, C.-C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus response correspondence. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 731-750.

Gratton, G., Coles, J., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General*, *121*, 480-506.

Eimer, M., & Schlaghecken, F. (1998). Effects of masked stimuli on motor activation: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1737-1747.

Frings, C., & Wentura, D. (2008). Trial-by-trial effects in the affective priming paradigm. *Acta Psychologica*, *128*, 318-323.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.

Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science*, *273*, 1699-1702.

Held, B., Ansorge, U., & Müller, H. (in press). Masked singleton effects. *Attention, Perception & Psychophysics*.

Jaśkowski, P., Skalska, B., & Verleger, R. (2003). How the self controls its „automatic pilot" when processing of subliminal information. *Journal of Cognitive Neuroscience, 15*, 911-920.

Kiefer, M., & Spitzer, M. (2000). Time course of conscious and unconscious semantic brain activation. *NeuroReport*, *11*, 2401-2407.

Kiefer, M., & Brendel, D. (2006). Attentional modulation of unconscious semantic processes: Evidence from event-related potentials in masked priming paradigm. *Journal of Cognitive Neuroscience, 18*, 1-15.

Kiefer, M., & Martens, U. (2010). Attentional sensitization of unconscious cognition: Task sets modulate subsequent masked semantic priming. *Journal of Experimental Psychology: General*, *139*, 464-489.

Kiesel, A., Kunde, W., & Hoffmann, J. (2006). Evidence for task-specific resolution of response conflict. *Psychonomic Bulletin & Review*, *13*, 800-806.

Kinoshita, S., & Hunt, L. (2008). RT distribution analysis of category congruence effects with masked primes. *Memory & Cognition*, *36*, 1324-1334.

Kouider, S., & Dupoux, E. (2004). Partial awareness creates the „illusion" of subliminal semantic priming. *Psychological Science*, *15*, 75-81.

Kunde, W. (2003). Sequential modulations of stimulus-response correspondence effects depend on awareness of response conflict. *Psychonomic Bulletin & Review*, *10*, 198-205.

Kunde, W., Kiesel, A., & Hoffmann, J. (2003). Conscious control over the content of unconscious cognition. *Cognition*, *88*, 223-242.

Kunde, W., & Wühr, P. (2006). Sequential modulations of correspondence effects across spatial dimensions and tasks. *Memory & Cognition*, *34*, 356-367.

Lau, H.C., & Passingham, R. E. (2007). Unconscious activation of the cognitive control system in the human prefrontal cortex. *Journal of Neuroscience*, *27*, 5805-5811.

Leuthold, H., & Kopp, B. (1998). Mechanisms of priming by masked stimuli: Inferences from event-related brain potentials. *Psychological Science*, *9*, 263-269.

Lingnau, A., & Vorberg, D. (2005). The time course of response inhibition in masked priming. *Perception & Psychophysics*, *67*, 545-557.

Lu, C.-H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review*, *2*, 174-207.

Macmillan, M. A., & Creelman, C. D. (2005). *Detection theory. A user's guide*. Mawah, NJ: Lawrence Erlbaum.

Mattler, U. (2003). Priming of mental operations by masked stimuli. *Perception & Psychophysics*, *65*, 167-187.

Mattler, U. (2005). Inhibition and decay of motor and nonmotor priming. *Perception & Psychophysics*, *67*, 285-300.

McCormick, P. A. (1997). Orienting attention without awareness. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 168-180.

Neumann, O., & Klotz, W. (1994). Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification? In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 123-150). Cambridge, MA: MIT Press.

Norris, D., & Kinoshita, S. (2008). Perception as evidence accumulation and Bayesian inference: Insights from masked priming. *Journal of Experimental Psychology: General*, *137*, 434-455.

Polat, U., & Sagi, D. (2007). The relationship between the subjective and objective aspects of visual filling-in. *Vision Reserch*, *47*, 2473-2481.

Proctor, R. W., & Vu, K.-P. L. (2002). Mixing incompatibly mapped location-irrelevant trials and location-relevant trials: Influence of stimulus mode on spatial compatibility effects. *Memory & Cognition*, *30*, 281-293.

Rensink, R. A. (2000). Seeing, sensing, and scrutinizing. *Vision Research*, *40*, 1469-1487.

Schlaghecken, F., & Eimer, M. (2004). Masked stimuli can bias "free" choices between response alternatives. *Psychonomic Bulletin & Review, 11,* 463–468.

Stürmer, B., Leuthold, H., Soetens, E., Schroeter, H., & Sommer, W. (2002). Control over location-based response activation in the Simon task. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 1345-1363.

Van Gaal, S., Lamme, V. A. F., & Ridderinkhoff, K. R. (2010). Unconsciously triggered conflict adaptation. *PLOS One*, *5(7)*: e11508.

Van Steenbergen, H., Band, G. P. H., & Hommel, B. (2009). Reward counteracts conflict adaptation: Evidence for a role of affect in executive control. *Psychological Science, 20*, 1473-1477.

Vorberg, D. (2009). Unterliegt unbewußte Informationsverarbeitung bewusster Kontrolle? [I unconscious information processing subject to conscious control?]. In A. B. Eder, K. Rothermund, S. R. Schweinberger, M. C. Steffens & H. Wiese (Eds.), *51. Tagung experimentell arbeitender Psycholog|innen in Jena* (p. 94). Lengerich, Germany: Pabst Science Publishers.

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. *Proceedings of the National Academy of Science, 100,* 6275–6280.

Wendt, M., Kluwe, R. H., & Peters, A. (2006). Sequential modulations of interference evoked by processing task-irrelevant stimulus features. *Journal of Experimental Psychology: Human Perception and Performance, 32*, 644 - 667.

Wühr, P., & Ansorge, U. (2005). Exploring trial-by-trial modulations of the Simon effect. *Quarterly Journal of Experimental Psychology, 58*A, 705-731.

Footnotes

[1] A similar ANOVA of the incorrect responses led to only significant main effects of congruence, $F(1, 44) = 19.11$, $p < .01$, with faster congruent RTs (752 ms) than incongruent RTs (767 ms), and of correspondence, $F(1, 44) = 104.33$, $p < .01$, with faster corresponding RTs (702 ms) than non-corresponding RTs (817 ms). The interactions between congruence and preceding congruence, $F(1, 44) = 2.71$, $p = .10$, and between masking, congruence, and preceding congruence failed, $F(1, 44) < 1.00$, suggesting that even in the aware conditions, conflict control depended on the participants' awareness of conflict in the preceding trial.

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Supported by Deutsche Forschungsgemeinschaft Grant An 393/3-2 to Ulrich Ansorge, and An 393/5-1 to Ulrich Ansorge, Werner Klotz and Ingrid Scharlau, within the Research Network "Neuro-Cognitive Mechanisms of Conscious and Unconscious Visual Perception" (PAK 270). Thanks to Friederike Schlaghecken and one anonymous Reviewer for excellent comments on a previous version of the manuscript and to Oliver Oberleitner, Quirin Stubbe, and Fritz Thausing for help with the data collection.

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6. Subcortical Human Face Processing

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Journal Publication Citation:

Khalid, S., Finkbeiner, M., König, P., & Ansorge, U. (2012). Sub-cortical Human Face Processing? Evidence from Masked Priming. *Journal of Experimental Psychology: Human Perception and Performance*. (DOI: 10.1037/a0030867)

Abstract

Face processing without awareness might depend on subcortical structures (retino-collicular projection), cortical structures, or a combination of the two. The present study was designed to tease apart these possibilities. Because the retino-collicular projection is more sensitive to low spatial frequencies, we used masked (subliminal) face prime images that were spatially low-pass filtered, or high-pass filtered. The masked primes were presented in the periphery prior to clearly visible target faces. Participants had to discriminate between male and female target faces and we recorded prime-target congruence effects – that is, the difference in discrimination speed between congruent pairs (with prime and target of the same sex) and incongruent pairs (with prime and target of different sexes). In two experiments, we consistently find that masked *low-pass* filtered face primes produce a congruence effect and that masked *high-pass* filtered face primes do not. Together our results support the assumption that the retino-collicular route which carries the low spatial frequencies also conveys sex specific features of face images contributing to subliminal face processing.
Keywords: Face processing; priming; subcortical; HSF; LSF

Introduction

Studies with cortically blind patients (de Gelder, Vroomen, Pourtois, & Weiskrantz, 1999) and with healthy human participants (Morris, Öhman, & Dolan, 1999) have demonstrated that humans can process faces in the absence of awareness (e.g., Dimberg, Thunberg, & Elmehed, 2000; Kiss & Eimer, 2008; for a review see Johnson, 2005; Palermo & Rhodes, 2007). For instance, Morris et al. found emotional processing of subliminal fearful faces. Likewise, researchers have observed subliminal priming effects in a sex-categorization task (Finkbeiner & Palermo, 2009).

Presently, however, it is still not clear which brain processes are responsible for unaware face processing. Authors like de Gelder et al. (1999) have argued for a subcortical origin of nonconscious face processing. They reported that patient GY with blindsight (i.e., visual processing of stimuli for which the patient is cortically blind) was able to discriminate emotional expressions of faces despite being unaware of the faces (see also Lee, Johansen-Berg, & Ptito, 2006; Pegna, Katheb, Lazeyras, & Seghier, 2005). The authors ascribed the capability of GY's unaware face perception to his intact projection from the retina to the cortex via the midbrain's superior colliculi (SC), just as this has been done for other forms of blindsight (Weiskrantz, 1986; Weiskrantz, Warrington, Sanders, & Marshall, 1974). Consistent with this midbrain account of face perception, Jolij and Lamme (2005) found that participants were able to discriminate the emotional expression (sad vs. happy) of subliminally presented schematic faces. Critically, Jolij and Lamme had used transcranial magnetic stimulation (TMS) over primary visual cortex to block the awareness of the face stimuli. Thus it is reasonable to think that the participants' successful discrimination did not arise from cortical processes and, instead, reflected subliminal processes that arose along the SC pathway (cf. Tamietto & de Gelder, 2010 for a review). In the following, we will refer to the possibility that subliminal face perception arises along the SC pathway as the *midbrain hypothesis*.

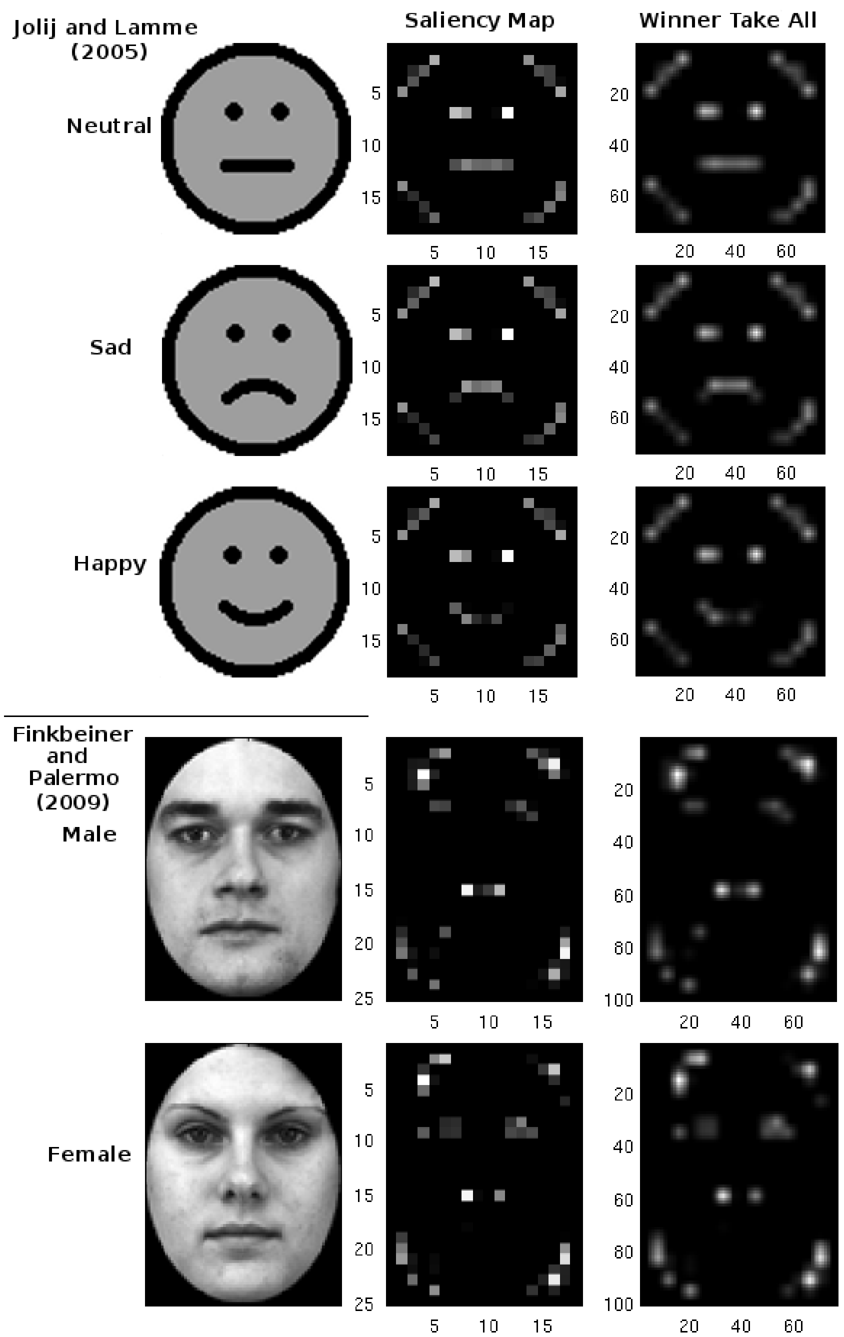

Figure 1: Saliency maps and Winner take all maps (Itti, Koch, & Niebur, 1998; Koch & Ullman, 1985; Walther & Koch, 2006) for emotional icon face stimuli used in Jolij and Lamme (2005) (upper panel), and for male and female face images (lower panel) used in Finkbeiner and Palermo (2009). Here, saliency is computed as the normalized summed feature difference in color, orientation, and intensity at each point of the image. In the Figure, the resulting saliency value and, thus, the likelihood of processing increases from black to white. It can be seen that the angry/sad face of Jolij and Lamme (2005) is more salient in the emotion-discriminating area of the bent lips than the happy face image. Saliency thus provides a confounding influence on subliminal processing that might have nothing to do with face processing in particular. However the male and female face images that were used by Finkbeiner and Palermo (2009) and in the current study have almost identical net salience. These face images do not differ with respect to saliency allowing safe conclusions about subliminal face-specific processing (in this case the processing of sex-related face differences). [Please note that in the current study we have created face prime images through high-pass and low-pass filtering the same male and female face prime images that were used by Finkbeiner and Palermo (2009).]

However, not all studies of subliminal face perception have implicated subcortical structures, finding instead modulations in the human cortex. It is well known that face processing is sub-served by cortical structures (cf. McCarthy, Puce, Gore, & Allison, 1997; for a review see Kanwisher & Yovel, 2006). Correspondingly, in an fMRI study with subliminal face primes, Kouider, Eger, Dolan, and Henson (2009) found activity changes in cortical structures (see also de Gardelle & Kouider, 2010; Dolan et al., 1996). In addition to the challenge presented by these fMRI studies, the midbrain hypothesis is also challenged by the difficulty in interpreting studies of subliminal emotional face processing. This is because different emotional expressions differ in their low-level visual salience (cf. Horstmann, Becker, Bergmann, & Burghaus, 2010). This fact is illustrated with an example in Figure 1. In this context, it is important to note that salience facilitates processing (Itti, Koch, & Niebur, 1998) and operates at subliminal levels (cf. Zhaoping, 2008). Therefore, faster processing of more salient stimuli than less salient stimuli in general could account for some effects that have been attributed to face-specific processing (cf. Santos, Mier, Kirsch, & Meyer-Lindenberg, 2010). Under this perspective processing differences between sad and happy faces, for example, would reveal little about face processing in particular. Also, the previous studies with respect to the midbrain hypothesis were mainly either based on complex imaging techniques with patients or TMS studies using schematic emotional faces, each having their own shortcomings, such as an individual's particular adaptation to the pathological conditions in patients (cf. Bridge, Thomas, Jbabdi, & Cowey, 2008) or the elicitation of interfering phosphenes during TMS stimulation of V1 (cf. Kammer, 2007).

Against this background, we tested the midbrain hypothesis using a psychophysical approach. As a task, we used the sex discrimination of faces. Male and female faces differ very little in their salience and thus overcome one important limitation of past research (see Figure 1). In the present psychophysical approach we presented real face images as masked (subliminal) primes in the periphery prior to visible target face images and asked our participants to discriminate the sex of the target faces. In two experiments we varied the spatial frequency of the prime faces, using high-pass filtered (HSF), and low-pass filtered (LSF) face primes. We also manipulated spatial attention by cueing the location of either the target or prime (c.f. Finkbeiner & Palermo, 2009). If the midbrain hypothesis is correct, then the masked LSF face primes should produce priming regardless of where spatial attention is focused. In contrast, the masked HSF face primes should not produce priming at least when these are not attended to. Thus the current study provides a relatively simple approach to test the midbrain hypothesis.

On each trial, we presented our participants with one male or female face as a clearly visible target. The participants had to press one button for a male, and another button for a female face. Prior to the target face, we presented a masked high-pass filtered or low-pass filtered face prime in the periphery (cf. Finkbeiner & Palermo, 2009). Masking efficiently blocks the awareness of a visual stimulus (Breitmeyer & Ögmen, 2006). Hence, we expected that the participants would be unable to report the masked face primes (tested in a 2AFC task). Following Finkbeiner and Palermo (2009), we expected to find a masked congruence effect in the low-pass filtered condition, whereby target classification latencies were shorter following a congruent prime (prime and target are the same sex) and longer following an incongruent prime.

To test the midbrain hypothesis of unaware face processing we did the following three things. First, we presented the prime stimuli in the periphery in order to increase the contribution of the face image's LSFs (low spatial frequencies) relative to its HSFs (high spatial frequencies). Our motivation hinges on the fact that in the visual periphery there is a substantial convergence of photoreceptors on their corresponding retinal ganglion cells. Importantly, the ganglion cells responsible for the periphery work as visual low-pass filters as they are only sensitive to relatively coarse spatial detail.

Second, these ganglion cells feed into the magno-cellular pathway projecting indirectly to the midbrain's SC (cf. Schiller, Malpeli, & Schein, 1979). Therefore, the midbrain projection is sensitive to the LSF band of the image. In this respect, the midbrain projection differs from the parvo-cellular projection. The parvo-cellular projection is more sensitive to the HSF band. Importantly, at subcortical levels, the parvo-cellular projection is largely segregated from the magno-cellular projection. The magno-cellular path indirectly projects to the midbrain, but the parvo-cellular projection bypasses the midbrain. The parvo-cellular pathway runs from the retina via the LGN (lateral geniculate nucleus) to the primary visual cortex (area V1) in the occipital lobe. Thus, a visual capacity relying on the midbrain projection should be achieved with LSF content from the visual periphery (Vuilleumier, Armony, Driver, & Dolan, 2003) but it could not be achieved with peripheral HSF content. Based on these characteristics we derived the following prediction. If unaware face processing can be driven by the midbrain projection, unaware face priming should be found with masked LSF but not with masked HSF face primes. For example, de Gardelle and Kouider (2010) recently reported subliminal face priming effects with HSF primes. However, they used a fame-judgment task and presented the subliminal faces at fixation. Thus, to test the possibility that subliminal face perception can be supported by sub-cortical projections, we chose to use a sex discrimination task. This is because sex discrimination processes rely primarily on LSF information (cf. Schyns & Oliva, 1999).

Third, we investigated the intriguing possibility that the masked congruence effect for HSF face primes might depend on the appropriate allocation of spatial attention. In the study by Finkbeiner & Palermo (2009), they found that masked congruence priming depended on spatial attention in tasks in which the perceptual discrimination was driven by HSF content (e.g. their animal/tool task done with line drawings). In contrast, in their sex-discrimination task with broad spectrum faces, they found that attention did not modulate the masked congruence effects. If the reason that their masked congruence effects for face stimuli did not depend on attention was because those effects were driven by LSF content, then it is reasonable to think that HSF faces would produce priming but, like non-faces, only when attended. We considered this possibility in the following experiments by manipulating the validity of a spatial cue for both LSF and HSF face stimuli.

Experiment 1

In Experiment 1, participants categorized visible target faces as either male or female. The target stimuli were preceded by HSF or LSF face primes. All primes were masked and presented in the periphery. The critical target stimuli were broad spectrum faces but we also included filtered HSF and LSF face targets on 10% of the trials. This was done so that we could assess participants' ability to categorize these stimuli under supraliminal conditions.

All primes were presented slightly shifted into the visual periphery and the targets were shown at a fixed position below the prime. Also, a cue captured attention either to the location of the upcoming prime or target (see Figure 3). If the midbrain hypothesis holds true, the LSF face primes, but not the HSF face primes, should produce a congruence effect in the target-cued (prime unattended) conditions. Furthermore, we considered the possibility that, in the prime-cued conditions, we would observe congruence effects with both LSF and HSF primes.

Method

Participants. Thirty students (23 female) with a mean age of 22.1 years participated. Here and in the following experiment, all participants had normal or corrected to normal vision. Also, informed consent was obtained from the participants, and the participants were treated in accordance with APA standards and the rules of the declaration of Helsinki. Participants received course credit for participation.

Apparatus. Visual stimuli were presented on a 15-inch, color flat screen display. Its refresh rate was 59.1 Hz and having NVIDIA GeForce GT 220 (with 1024 MB) graphics adapter. The pictures that we presented were quite small in size. A typical stimulus (backward mask + target) had dimensions of 75w x 216h pixels and sized 17.0KB. However, to avoid any buffer overload problem, all the stimuli were loaded offline only once and pointers to them were used in the experiment trials. Matlab with Psychophysics toolbox -3 was used. Further, care was taken for correct stimulus presentation duration and the slack caused by the display (calculated from the flip interval of the display), and the inter stimulus interval (ISI) was kept zero. Accurate timing of the display was verified by measurement with an oscilloscope. This was achieved by repeatedly presenting the stimuli for their original duration one by one and recording their duration through a cathode ray oscilloscope. We found that in all cases of our stimuli the precision of presentation duration was better than one millisecond.

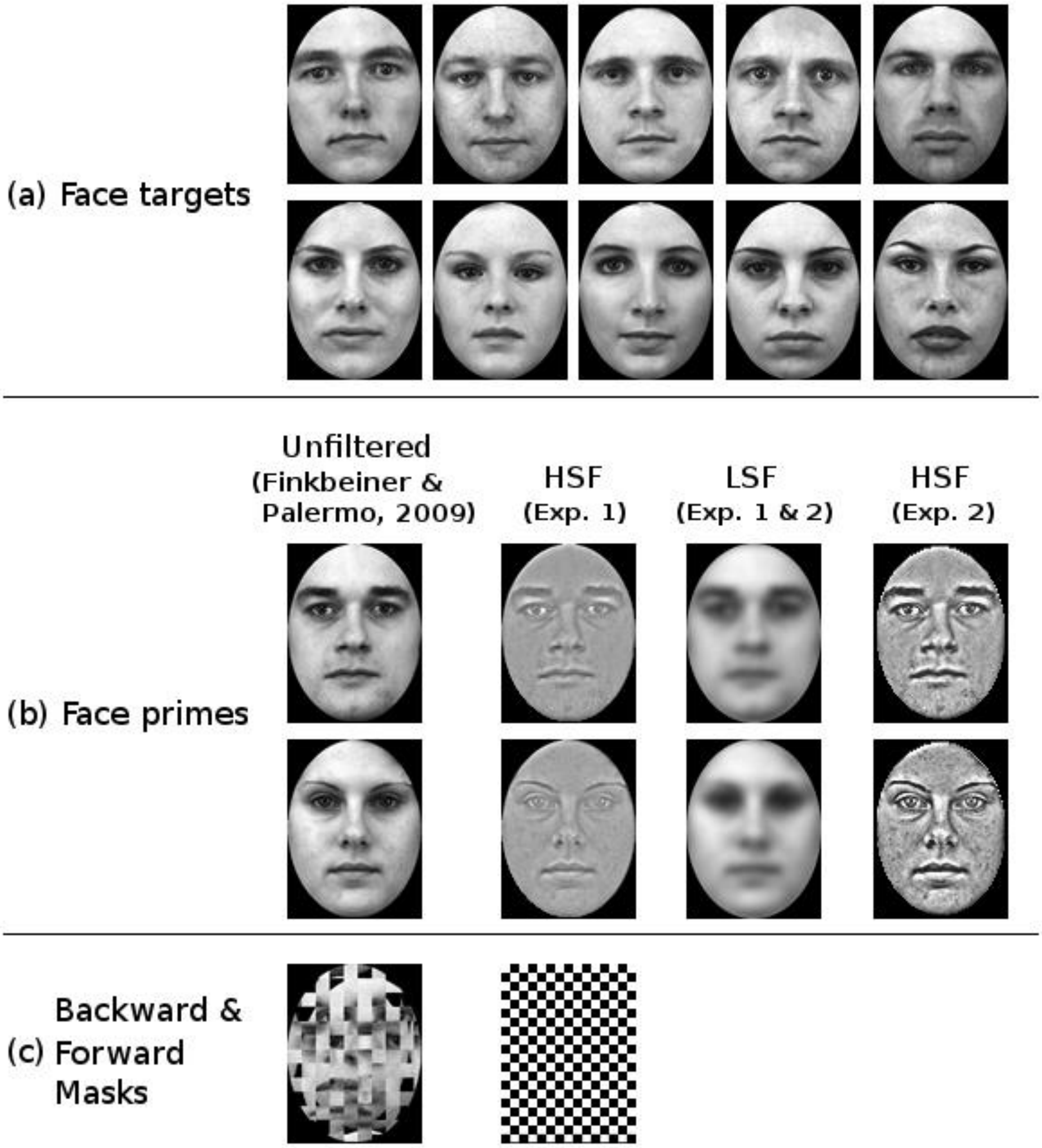

Figure 2: Panel (a): set of male and female face targets. Panel (b): set of face primes; from left to right: unfiltered face primes used in Finkbeiner and Palermo (2009), high-pass filtered (HSF) face primes used in Experiment 1, low-pass filtered (LSF) face primes used in Experiments 1 and 2, and high-pass filtered face primes used in Experiment 2. Panel (c): the backward mask (a scrambled composite face), and the forward mask (a checkerboard pattern).

The participants sat at a distance of 57 cm from the screen in a quiet, dimly lit room, with their head resting in a chin rest to ensure a constant viewing distance and a straight-ahead gaze direction. Reaction times (RTs) were registered via the standard serial computer keyboard, placed directly in front of the participants. Target responses were registered through the keys ‘A’ and ‘L’ (covered and labeled as ‘left’ and ‘right’, respectively). The participants put their left and right index fingers on the correspondingly labeled keys. After reading the instructions the participants pressed the spacebar with one of their thumbs to start the experiment, and after each trial to continue. In this way, the participants could also take breaks at their convenience by simply not pressing the space bar.

Stimuli. We used the masks, cues, target face stimuli, and high-pass filtered and low-pass filtered versions of the face prime images of Finkbeiner and Palermo (2009). The face targets and the face primes wore neutral emotional expressions and were originally taken from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist, Flykt, & Öhman, 1998). All face stimuli were equated for luminance and contrast. To filter the prime faces, first, these were equated for foreground-background luminance and contrast. Next, we high-pass filtered and low-pass filtered the equated face primes to get the HSF and LSF face primes respectively. During filtering it was insured that each HSF and LSF image contained exactly the corresponding sub-portion of frequencies of the original unfiltered image. The resultant filtered face images were then re-cropped behind the oval layer. (All image processing was performed in MATLAB, and high-pass and low-pass filtering functions were implemented from Gonzalez, Woods, & Eddins [2004].) The resultant HSF and LSF prime faces can be seen in Figure 2’s panel (b).

We also included 10% filler trials (analyzed separately) in which the HSF and the LSF primes were used as targets. These filler trials were randomly intermixed with the unfiltered face target trials to ensure that participants did not only search for the LSF content of the unfiltered face targets but also for the HSF content (cf. Ansorge, Horstmann, & Worschech, 2010).

All of the face stimuli were cropped in an oval layer so that only the face features were presented. Each image subtended a visual angle of 3.0° vertically and 2.5° horizontally. The forward mask was a checkerboard pattern. The backward mask was a scrambled composite of the two unfiltered face primes.

Procedure. See Figure 3 for examples of a sequence of events in a trial. Stimuli were presented on a black screen (luminance < 0.1 cd/m^2). In each trial, two streams of stimuli were presented, one stream directly above the other, with the target at a fixed position and the prime above it.

Each trial began with a checkerboard mask for 500ms. Next, an unpredictable cue was shown at either prime or target location, together with the checkerboard mask at the non-cued location, for 50ms. The cue was used to capture attention towards the prime (in the prime-cued condition) or to the target (in the target-cued condition). After this, the checkerboard mask was shown again at both positions for 50ms, followed by the prime face at the upper position together with the checkerboard mask at the target’s position for 50ms. The two face primes, one male and one female, were taken from different individuals than the face targets to avoid repetition priming (Forster & Davis, 1984; Norris & Kinoshita, 2008). In the final frame, the target face was presented in the lower location for 300ms and a scrambled-face backward mask was presented in the upper (prime) location.

Across trials, prime and target sex varied orthogonally to create congruent and incongruent conditions. In the congruent conditions, the prime face sex was the same as the target face sex. Either a male face prime was presented prior to a male face target, or a female face prime was presented prior to a female face target. In the incongruent conditions, the prime face’s sex was different from the target face’s sex. Either a male face prime was presented prior to a female face target, or a female face prime was shown prior to a male face target.

In the target discrimination task, participants had to discriminate the sex of the target faces by pressing one of the assigned buttons (counter balanced across participants). The target discrimination task consisted of two blocks, one with HSF primes and the other one with LSF primes. The sequence of the two target-discrimination blocks was also counter balanced across the participants. Each of the two target discrimination blocks consisted of 20 repetitions of each combination of cueing (prime-cued, target-cued), target type (male, female), and prime-target congruence level (congruent, incongruent), for a total of 160 trials. Additional filler trials with HSF and LSF face targets (16 per condition) were interleaved in each block.

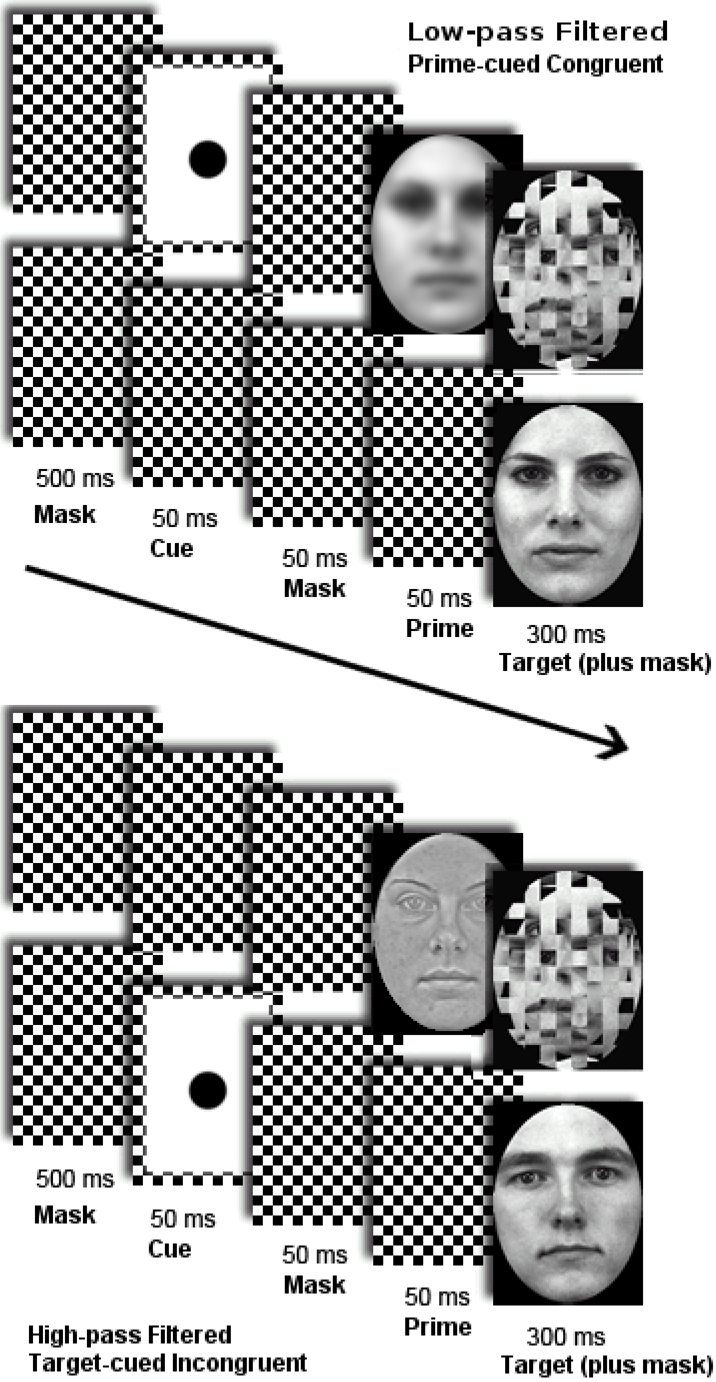

Figure 3: Upper panel: Depicted is a sequence of stimuli with a low-pass filtered face prime in a prime-cued congruent trial of Experiment 1. (The same conditions were used in Experiments 2.) Lower panel: Depicted is a sequence of stimuli with a high-pass filtered (HSF) face prime in a target-cued incongruent trial of Experiment 1. Arrows depict the flow of time.

At the end of the experiment, participants performed one block of trials in which they had to categorize the masked primes. For this prime-discrimination task, participants first categorized the visible target (just as they had in the experiment proper) and then they categorized the masked prime.

The same sex-to-response-button mapping was used for the prime faces as for the target faces. The prime-discrimination task consisted of another 200 trials, 100 trials with LSF face primes, and the other 100 trials with HSF face primes.

Within each block, the different conditions were realized in pseudo-random sequence, with the two constraints that no particular face target was repeated in immediately succeeding trials and that no more than four trials in a row required the same target response. The experiment started with the target discrimination block, followed by the masked prime-discrimination block. A block of 80 trials with unmasked face primes of 50ms duration was included at the very end of the experiment in which only the primes were presented at their location (upper panel). This final block was included to verify that the HSF or the LSF prime content alone had been sufficient to allow successful sex discrimination under aware conditions. In this final block, all of the masks (checkerboards and composites of scrambled faces) and the targets were left out (i.e., all these stimuli were replaced by blank screens) and the participants were asked to discriminate between the sexes of the unmasked prime faces. The experiment was run in a single session, with five short breaks, one in the middle of each block plus one after each of the first 2 blocks. The whole experiment took approximately 1 hour.

Results

Target-discrimination task. For our first analysis, only correct target responses were considered. (The filler trials, and the erroneous trials were analyzed separately, see below.) The mean RTs are depicted in Figure 4 and also detailed in Table 1. As can be seen in Figure 4, we found a congruence effect with the LSF primes (circular symbols) in both target-cued (filled symbols) and prime-cued (unfilled symbols) conditions, but not with the HSF primes (triangular symbols).

This was confirmed by formal analysis. Mean RTs for each participant and condition were calculated, and trials that were faster or slower than 2.5 standard deviations of the mean were discarded (3.5%). An omnibus repeated-measures ANOVA was run with the within-participant variables prime type (LSF prime vs. HSF prime), cue type (target-cued vs. prime-cued), and prime-target congruence (congruent vs. incongruent). Bonferroni adjustments for multiple comparisons and the alpha level of .05 for all statistics were applied here and throughout the study.

We found a significant two-way interaction of the variables prime type and congruence, $F(1,29) = 10.23$, $p < .01$, partial $\eta^2 = 0.26$. This showed overall net congruence effects of 4ms and 6ms in the target-cued and prime-cued conditions respectively with the LSF primes which dropped respectively to 0ms and -5ms with the HSF primes (see Table 1). This interaction was also further investigated by follow-up analyses (see below).
We also found a significant main effect of cue type, $F(1,29) = 41.18$, $p < .001$, partial $\eta^2 = 0.59$. RTs were shorter in the target-cued condition (M = 494ms) than in the prime-cued condition (M = 504ms). No other significant effect or interaction was found, all Fs < 1.00. To note, there was also no three-way interaction of prime type, cue type, and congruence, as would be expected on the basis of congruence effects (1) in prime- and target cued LSF conditions as well as (2) prime-cued HSF conditions (3) but not target-cued HSF conditions.

A follow-up ANOVA of the HSF condition with the within-participant variables cue type and congruence revealed only a significant main effect of the variable cue type, $F(1,29) = 21.88$, $p < .001$, partial $\eta^2 = 0.43$. The participants performed faster in the target-cued (M = 497ms) than in the prime-cued (M = 506ms) condition. However, a similar follow-up ANOVA of the LSF condition showed a significant main effect of congruence, $F(1,29) = 6.92$, $p < .02$, partial $\eta^2 = 0.19$, in addition to the significant main effect of cue type, $F(1,29) = 22.03$, $p < .001$, partial $\eta^2 = 0.43$. With the LSF primes, participants performed faster in the congruent condition (M = 494ms) as compared with the incongruent condition (M = 499ms). The performance was also faster in the target-cued condition (M = 492ms) than in the prime-cued condition (M = 501ms). To note, there was no two-way interaction of cue-type and congruence in this follow-up as well as in the omnibus ANOVA, both *F*s < 1.00. This showed that the congruence effect by the LSF primes was independent of shifting attention to the primes. Attention-independence of the subliminal priming effect was predicted on the basis of classical theory of subliminal processing (cf. Posner & Snyder, 1975). Attention-independence of the LSF-based priming effect is also in agreement with the refined position by Finkbeiner and Palermo (2009) according to which the subliminal LSF priming effect is considered to be attention-independent.

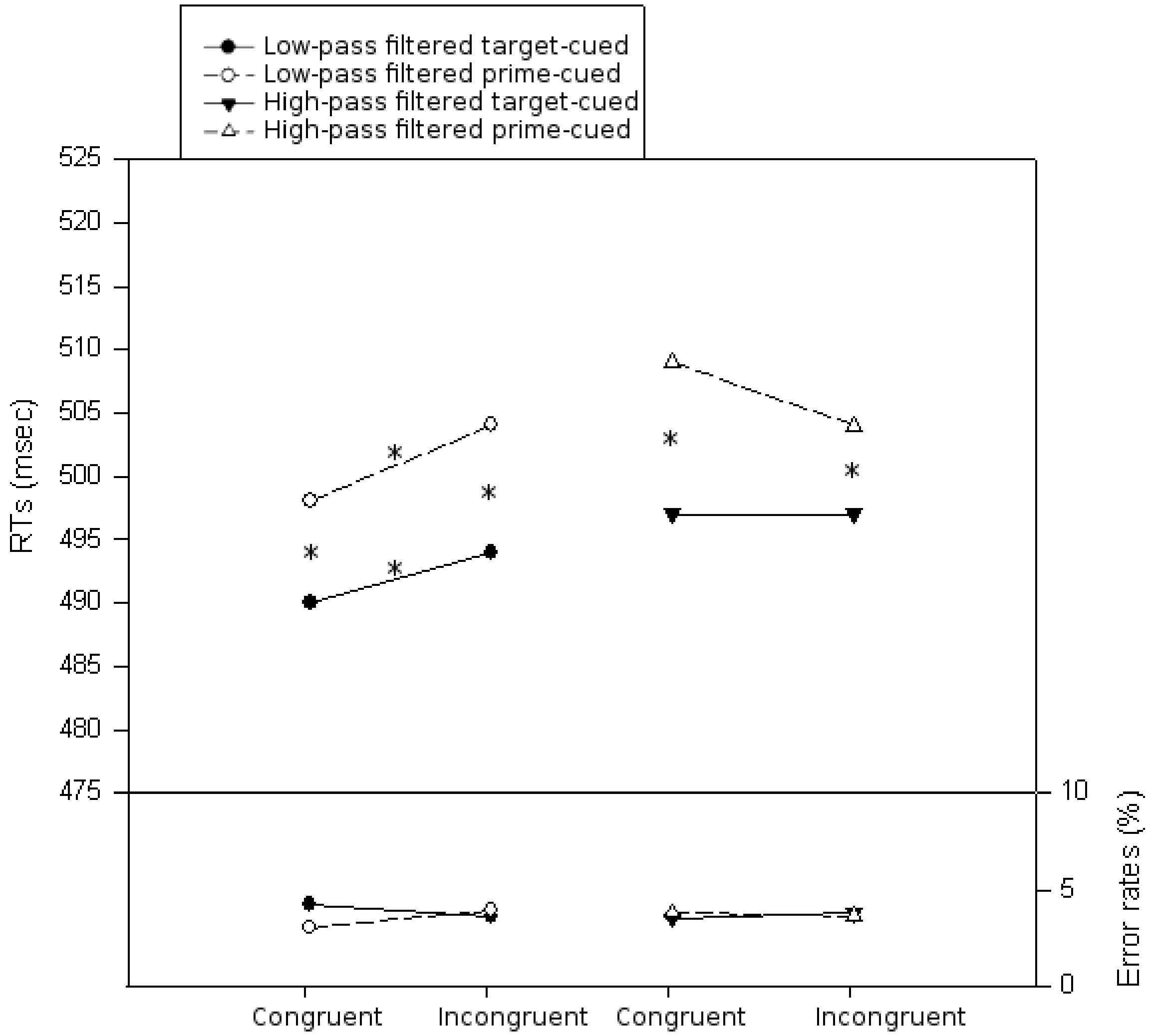

Figure 4: Mean Reaction Times (RTs) in milliseconds (upper panel) and error rates in percent (lower panel) on the y axis plotted as a function of congruence (congruent vs. incongruent), cue type (target-cued vs. prime-cued), and prime type (low-pass filtered [LSF] vs. high-pass filtered [HSF]) in Experiment 1 on the x axis (low-pass filtered = circles; high-pass filtered = triangles; target-cued = solid lines and filled symbols; prime-cued = dashed lines and unfilled symbols). Congruence effects can be seen in the RTs of both the target-cued and prime-cued conditions of the low-pass filtered (LSF) masked priming condition. Details about the mean RTs and error rates in each of the conditions and results of the analysis of the prime's visibility are summarized in Table 1. A star (*) shows the significant effects of congruence (when it appears in the middle of a line) or cue type (when two starts appear each between the starting and the ending points of lines).

Error rates. The same omnibus ANOVA was conducted separately with both percent and arcsine transformed error rates. No significant effect or interaction was found in any of the two ANOVAs, all *F*s < 1.00, and all *p*s > .05. Mean error rates can be seen in Figure 4 and Table 1.

Filler trials. Participants successfully discriminated the sex of the prime faces used as targets in the filler trials of both, the HSF condition (*M* = 85.0%, *SE* = 2.2), $t(29) = 16.10$, $p < .001$, and the LSF condition (*M* = 78.5%, *SE* = 2.1), $t(29) = 13.38$, $p < .001$.

Distribution analysis. We were concerned that a residual mean congruence effect of the masked HSF primes could be found in only the fastest responses. As can be seen from Figure 5, this was not the case.

Formally, this assumption was corroborated in the following way. Correct RTs of each condition were sorted in an ascending order from fast to slow responses, and the resulting RT distribution was then split into 4 quartiles (bins). Taking the mean RT from each of these quartiles, we repeated the omnibus ANOVA as described above but with the additional variable quartile (or bin) of the RT distribution (1, 2, 3, 4). Besides the above mentioned significant effects and interactions of our variables, we did not find any other significant effect or interaction, all *F*s < 1.00.

Table 1. Mean reaction times (RTs), error rates, and results of prime visibility tests for the conditions of Experiment 1. Mean RTs and error rates are compared in the congruent and incongruent conditions and the net congruence effect is calculated as the mean performance in the incongruent condition minus the mean performance in the congruent condition. Standard errors from the mean values are also provided. The results of *t*-tests against zero are given together with the mean *d'* values, averaged across congruent and incongruent conditions (Finkbeiner & Palermo, 2009). The degrees of freedom for all *t*-tests of the mean *d'*s were 29. The numbers in bold font indicate significant results. [LSF = Low-pass filtered; HSF = High-pass filtered; Congr. = Congruence; Cong. = Congruent; Incon. = Incongruent; Std. Err. = Standard Error; Sig. = Significance].

Conditions			**Reaction Times (ms)**			**Error rates (%)**			**Prime's visibility**			
Primes	Cue-Type	Congr.	Mean RTs	Std. Err.	Net Congr.	Mean Error rates	Std. Err.	Net Congr.	Mean *d'* (Cong & Incon)	Std. Err.	*t*-test against 0	sig. (2-tailed)
LSF	Target	Cong.	490	8	**4**	4.1	0.6	-0.6	-0.05	0.09	-0.57	.57
		Incon.	494	8		3.5	0.7					
	Prime	Cong.	498	8	**6**	2.9	0.6	0.9	0.10	0.07	1.42	.17
		Incon.	504	9		3.8	0.7					
HSF	Target	Cong.	497	8	0	3.4	0.5	0.3	-0.01	0.08	-0.06	.96
		Incon.	497	8		3.7	0.5					
	Prime	Cong.	509	8	-5	3.7	0.6	-0.2	-0.10	0.09	-1.11	.28
		Incon.	504	8		3.5	0.6					

Prime visibility. Prime visibility was assessed in the prime-discrimination task using *d'* from signal detection theory (SDT). *d' scores* were obtained from direct calculation of hit rates and false alarm (FA) rates (cf. Green & Swets, 1966). In the current study, 'male' primes were taken as 'signals' and 'female' primes as 'noise'. Here, *d'* is the *z*-transformed FA rate subtracted from the *z*-

transformed hit rate. This index becomes zero in the case of chance performance and it can infinitely increase with ever increasing discrimination performance. One-sample *t*-tests with zero indicated that the participants were not aware of the sex of the masked primes (Table 1). Results showed that mean *d'*s were neither significantly different from zero in the masked HSF target-cued condition (M = -0.01), $t(29) = -0.06$, $p > .95$, nor in the masked HSF prime-cued condition (M = -0.10), $t(29) = -1.12$, $p > .27$. Similarly, mean *d'*s were neither significantly different from zero in the masked LSF target-cued condition (M = -0.05), $t(29) = -0.57$, $p > .57$, nor in the masked LSF prime-cued condition (M = 0.10), $t(29) = 1.42$, $p > .16$. We additionally performed chi-square tests for the target-cued and prime-cued LSF priming and HSF priming conditions. However, all of the results were non-significant, *p*s > .99, too.

Unmasked prime discrimination. The participants were able to successfully discriminate the sex of the prime faces in both unmasked HSF (M = 90.4%, SE = 1.5), $t(29) = 26.14$, $p < .001$, and unmasked LSF (M = 78.0%, SE = 2.8), $t(29) = 10.21$, $p < .001$, conditions. Moreover, the discrimination of the HSF primes was significantly better than that of the LSF primes, $t(29) = 5.43$, $p < .001$.

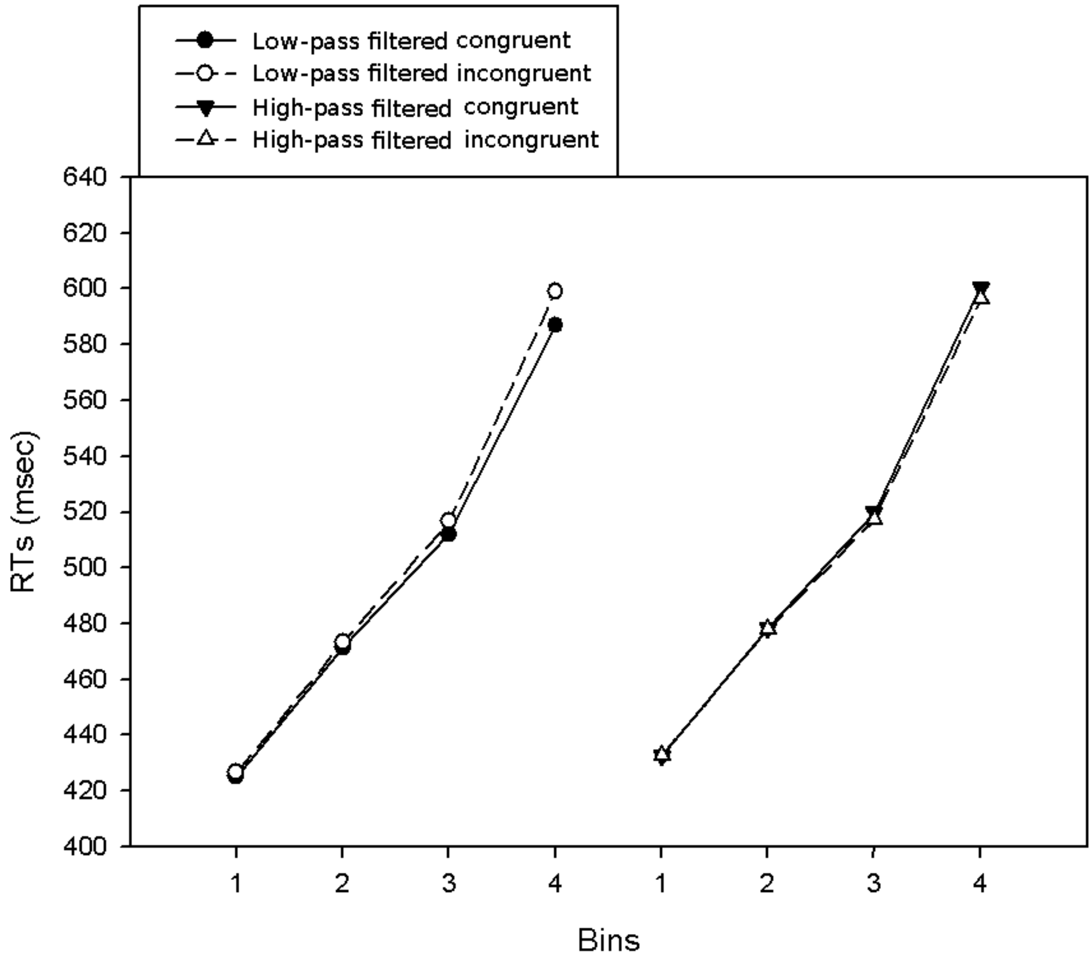

Figure 5: Mean Reaction Times (RTs) in milliseconds on the y axis plotted as a function of the quartile of the RT distribution (1st to 4th bin), prime type (low-pass filtered [LSF] vs. high-pass filtered [HSF]), and congruence (congruent vs. incongruent) in Experiment 1 on the x axis (congruent = solid lines and filled symbols; incongruent = dashed lines and empty symbols; circles = low-pass filtered [LSF] priming condition; triangles = high-pass filtered [HSF] priming condition). The congruence effect in LSF priming condition did not vary across bins.

Discussion

The results of Experiment 1 showed that only the masked LSF primes produced a congruence effect. Importantly, all prime faces were equated for foreground-background luminance before filtering. Yet, we were not able to demonstrate the congruence effect of the masked HSF primes even in the prime-cued condition. The masked HSF primes led to no congruence effect at all. These results are consistent with the midbrain hypothesis. The results clearly indicated that the effective processing of the peripheral masked face primes depended on the type of spatial frequencies contained within them. When the face primes were low-pass filtered and thus contained only LSF bands, the faces were processed sufficiently to modulate the classification responses to the subsequent face targets. Further, in line with an assumed origin of the effects in peripheral vision, the congruence effect by the low-pass filtered face primes was independent of shifting visual attention to the prime's location or to the target's location. Similar results were also observed by Finkbeiner and Palermo (2009) for unfiltered (LSF + HSF) primes. Also, as can be seen in the participants' prime discrimination performance, our participants remained unaware of the masked primes' sex. Taken together the unawareness of the face primes and the dependency of their priming effect on LSF content neatly dovetail with prior assumptions that unaware face processing could be brought about by the retino-collicular projection (cf. Finkbeiner & Palermo, 2009). The results are thus also in line with the more general claim for a rapid subcortical route devoted to the processing of highly relevant perceptual input (LeDoux, 1996, 1998; Merigan & Maunsell, 1993; Morris et al., 1999; Öhman, 2002; Palermo & Rhodes, 2007).

Moreover, the high discrimination rates of the HSF targets in the filler trials and that of the unmasked HSF primes in the control task at the end of the experiment showed that the participants comfortably discriminated the visible HSF prime sexes even more than they discriminated LSF prime sex (see de Gardelle & Kouider, 2010). This result confirms that foveal presentation of the HSF primes without masking allows for their processing, but that presentation in the periphery and masking jointly prevented HSF priming.

Experiment 2

One problem in Experiment 1's HSF primes was a difference in the luminance and contrast and spectral power between HSF and LSF primes (see Figure 6). The pixels distribution in various gray levels indicates the contrast of an image. When the pixels are distributed over a wide range of gray levels, the image has more contrast. As can be seen in Figure 6 the pixels in the HSF primes of Experiments 1 are distributed over a narrow range of gray levels. In contrast, the pixels in the LSF primes of Experiment 1 are distributed over a wider range of gray levels. This lead to a lower contrast of the HSF primes of Experiments 1 as compared to the LSF primes.

To overcome this problem, the extreme (dark and light) luminance values of the luminance distributions of Experiment 1's HSF primes were boosted proportional to attenuating their respective darker and lighter gray luminance value counterparts in the central area of the distribution of the luminance values. As a consequence, Experiment 2's HSF and LSF primes have almost identical contrasts and spectral powers (see Table 2, Figure 6, Figure 7, and panel (b) of Figure 2).

The resulting frequency distributions can be found in Figure 7. It can be seen that the HSF primes in Experiment 1 (green broken line) had a lower overall spectral power when compared to the LSF primes (red dotted line). However the spectral power of HSF primes in Experiment 2 (black broken and dotted line) is boosted and their mean amplitude is almost equal to that of the LSF primes (see Table 2).

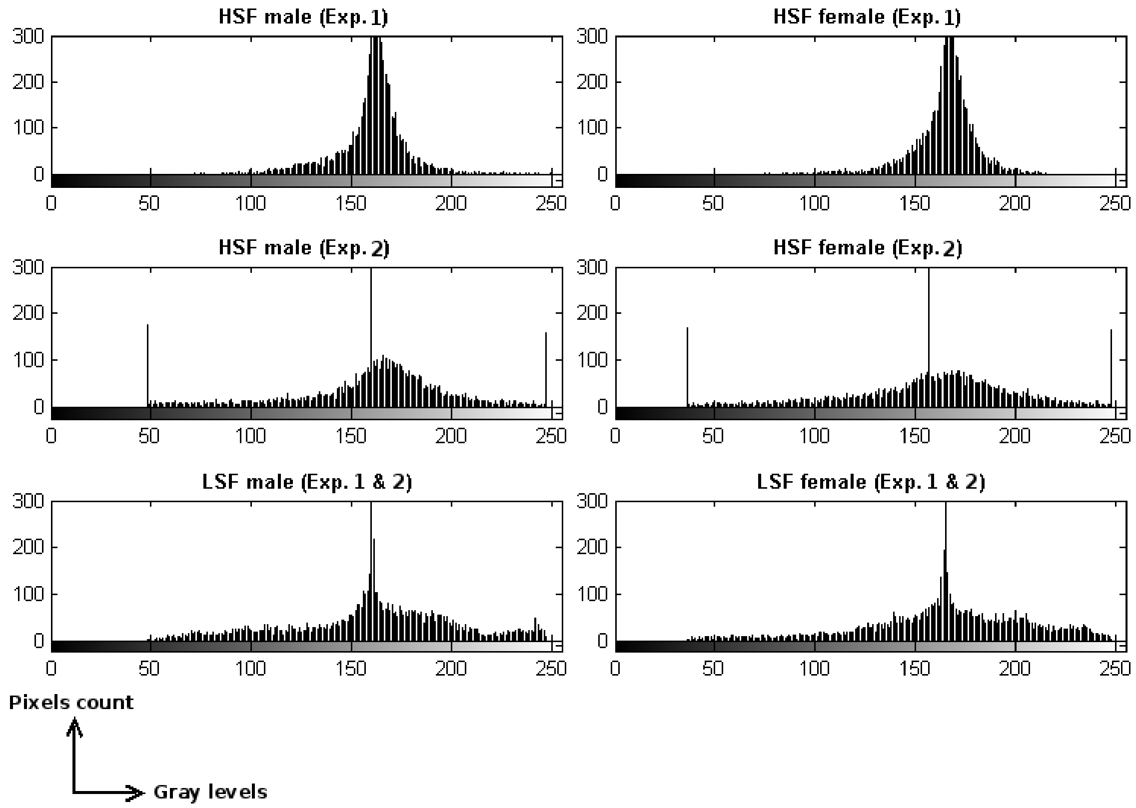

Figure 6: Pixel counts on the y axis as a function of their gray levels on the x axis. The gray level of the pixels is a measure of their luminance and can attain any value from zero (black) to 255 (white). The pixels distribution across the gray levels varies directly with an image contrast. The more broadly distributed the pixels are across the gray levels, the more contrast the image has and vice versa. When compared to HSF primes in Experiment 1 (panels in the 1st row), the gray levels of the majority of the pixels in the HSF primes in Experiment 2 (panels in the 2nd row) are broadly distributed and more similar to LSF primes in Experiment 1 and 2 (panels in the 3rd row). Please also note that the lower and upper limits of HSF primes in Experiment 2 and LSF primes in Experiments 1 and 2 are equal. Thus the two classes of primes in Experiment 2 have almost identical contrast as can also be verified in Table 2.

Table 2. Measures of the contrast and spectral power for primes used in Finkbeiner and Palermo (2009) and the current study. It can be seen that the HSF primes in Experiment 1 have a lower contrast and spectral power when compared to the corresponding unfiltered and LSF primes. By contrast, the HSF primes in Experiment 2 and the LSF primes in Experiments 1 and 2 have almost identical mean contrast and mean spectral power.

Primes	**Contrast (root mean square deviation)**			**Spectral Power (mean amplitude)**		
	Male	Female	Mean	Male	Female	Mean
Unfiltered (Finkbeiner & Palermo, 2009)	15.84	15.33	15.59	10.59	10.70	10.65
HSF (Exp. 1)	5.29	4.55	4.92	2.90	2.73	2.82
HSF (Exp. 2)	12.94	14.07	13.51	7.28	8.44	7.86
LSF (Exp. 1 & 2)	13.24	13.09	13.17	7.71	7.99	7.85

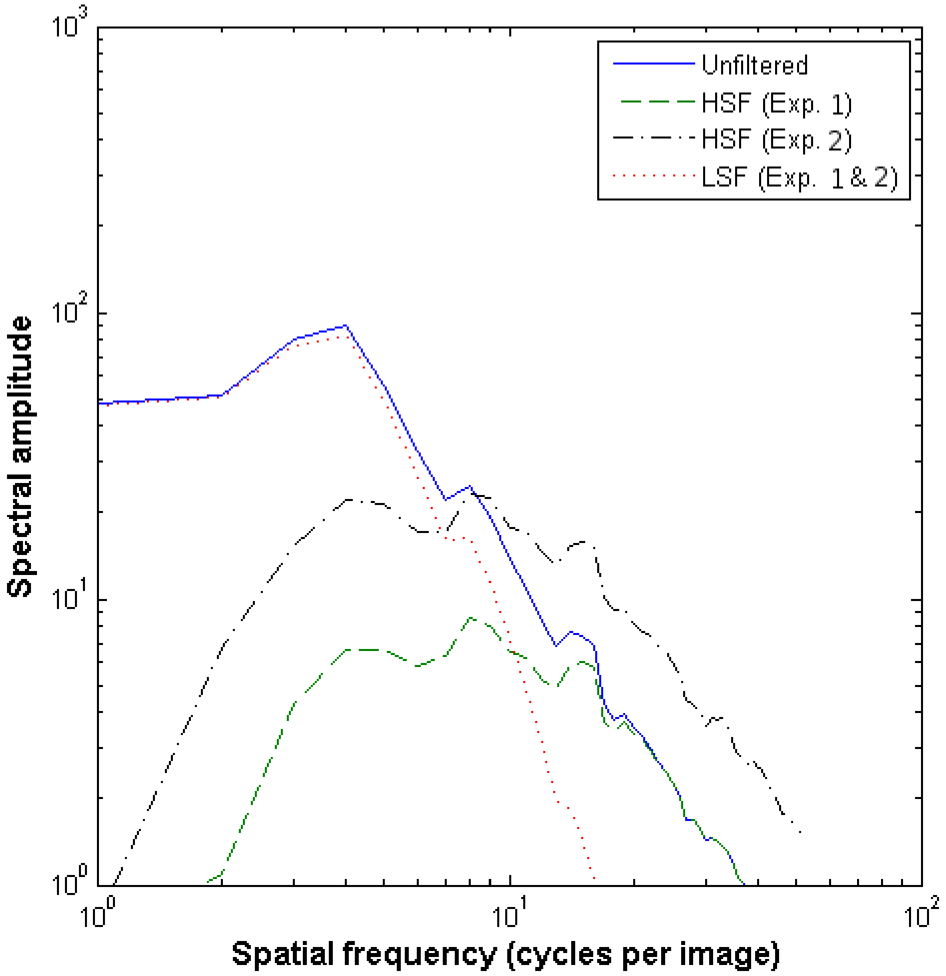

Figure 7: Log-log plots of radially averaged Fourier spectral amplitude on the y axis as a function of spatial frequency (in cycles per image) on the x axis (c.f. Graham & Redies, 2010; Olshausen & Field, 1996) for unfiltered face primes (blue solid line) used in Finkbeiner and Palermo (2009), HSF primes used in the current study's Experiment 1 (green broken line), HSF primes in Experiment 2 (black dotted and broken line), and LSF primes in Experiment 1 and 2 (red dotted line). Each line represents an average of the plots for male and female face images. The HSF primes have zero power in the initial frequencies and high power in the higher frequencies, while the LSF primes show high power in the low frequencies and no power in the high frequencies. The mean spectral power of HSF primes in Experiment 2 was identical to the mean spectral power of the LSF primes in Experiments 1 and 2, as can also be verified in Table 2.

A second shortcoming or uncertainty of Experiment 1 concerned our participants' eye-fixations. In Experiment 1, we did not record eye-movements. However, according to the rationale of the present study, it is mandatory that the participants fixate on the targets so that the primes are seen with parafoveal vision. Therefore, we took the opportunity to record the eye movements in one group of participants of Experiment 2 to verify that the participants indeed fixated the targets in a majority of the trials, and to test whether we can replicate the findings if we restrict the analyses to the trials in which the targets were fixated.

The predictions for this experiment were the same as before. With the masked LSF primes, we again expected a congruence effect regardless of whether the cue directed attention toward the primes or toward the targets. With the masked HSF primes, we expected no overall congruence effect but potentially one after directing attention to these primes (in the prime-cued masked HSF condition).

Method

Participants. Seventy students in total, thirty in Group 1 (23 female) with a mean age of 22.8 years, and forty in Group 2 (33 female) with a mean age of 24.6 years participated.

Apparatus, stimuli, and procedure in Group 2 (N = 40) were similar to Experiment 1 except that the contrast- and power-enhanced HSF primes, as shown in Figure 2's panel (b) were used. (The LSF primes were the same as in Experiment 1. Again different prime types were presented in different blocks and to the same participants.)

For Group 1 (N = 30), eye-movements were recorded. Here, the stimuli were presented on a 15-inch, color CRT monitor on a standard computer with a standard keyboard. The monitor's refresh rate was 59.1 Hz. The stimuli presentation timings of the monitor were tested through the oscilloscope as in Experiment 1, and the precision was again better than 1ms. The participants sat at a distance of 57 cm from the screen in a quiet, dimly lit room, with their head resting in a chin rest to ensure a constant viewing distance and a straight-ahead gaze direction. Eye movements were recorded via the SR Research Ltd. Eye-Link 1000 eye tracker. Gaze position was sampled at a rate of 1000 Hz. Monocular tracking was used and the best calibrated eye was recorded. Otherwise the conditions and procedure were as for Group 2.

Results

Target-discrimination task. Mean correct RTs are depicted in Figure 8 (for additional details see also Table 3). It is clear from Figure 8 that the LSF primes (circular symbols) elicited a congruence effect, but the HSF primes (triangular symbols) failed to do so.

These results were supported by our ANOVA. Of all correct responses, 3.8% were excluded based on the same outlier criterion as was used in Experiments 1. Further, in Group 1 only the trials in which the target was fixated (71.7%) were included. The remaining trials in Group 1, in which the prime was fixated (3.2%), a gaze-position error exceeding 0.5° after calibration was recorded, or with eye blinks (25.1%) were excluded. The percentage of trials thus included in each condition can be seen in Table 3.

The omnibus repeated-measures ANOVA of the correct mean RTs with the within-participant variables prime type (HSF vs. LSF prime), cue type (target-cued vs. prime-cued), prime-target congruence (congruent vs. incongruent), and a between-participants variable Group (1: only target fixated vs. 2: control) led to a significant two-way interaction of the variables prime type and congruence, $F(1,69) = 14.49$, $p < .001$, partial $\eta^2 = 0.18$. (For the sizes of different congruence effects see Table 3.) This interaction was also further investigated by follow-up analyses (see below).

Also, we found an overall effect of congruence, $F(1,69) = 5.89$, $p < .02$, partial $\eta^2 = 0.08$. Performance was faster in the congruent condition (M = 496ms) than in the incongruent condition (M = 499ms). Further, we again found a significant main effect of cue type, $F(1,69) = 40.39$, $p < .001$, partial $\eta^2 = 0.37$. RTs were shorter in the target-cued condition (M = 494ms) than in the prime-cued condition (M = 501ms). No other significant effect or interaction was found, all Fs < 1.00.

A follow-up ANOVA of the HSF condition with the within-participant variables cue type, and congruence, and the between-participants variable Group revealed again only a significant main effect of the variable cue type, $F(1,69) = 18.58$, $p < .001$, partial $\eta^2 = 0.22$. The participants performed faster in the target-cued (M = 496ms) than in the prime-cued (M = 503ms) condition. However, a similar follow-up ANOVA of the LSF condition showed a significant main effect of congruence, $F(1,69) = 25.01$, $p < .001$, partial $\eta^2 = 0.27$, reflecting that the participants performed faster in the congruent condition (M = 493ms) as compared to the incongruent condition (M = 498ms). Further, again, with the LSF condition, we found a significant main effect of cue type, $F(1,69) = 19.73$, $p < .001$, partial $\eta^2 = 0.23$, owing to faster performance in the target-cued condition

(M = 493ms) than in the prime-cued condition (M = 499ms). No other significant main effect or interaction was found, all Fs < 1.00.

Error rates. The same omnibus ANOVA was conducted with both, percent error rates and arcsine transformed error rates. No significant effect or interaction was found, all Fs < 1.00. Mean percent error rates can be found in Figure 8 and Table 3.

Filler trials. Participants successfully discriminated the sex of prime faces used as targets in the filler trials of both, the HSF condition (M = 80.2%, SE = 1.7), $t(69) = 17.50$, $p < .001$, and the LSF condition (M = 76.3%, SE = 1.5), $t(69) = 17.39$, $p < .001$.

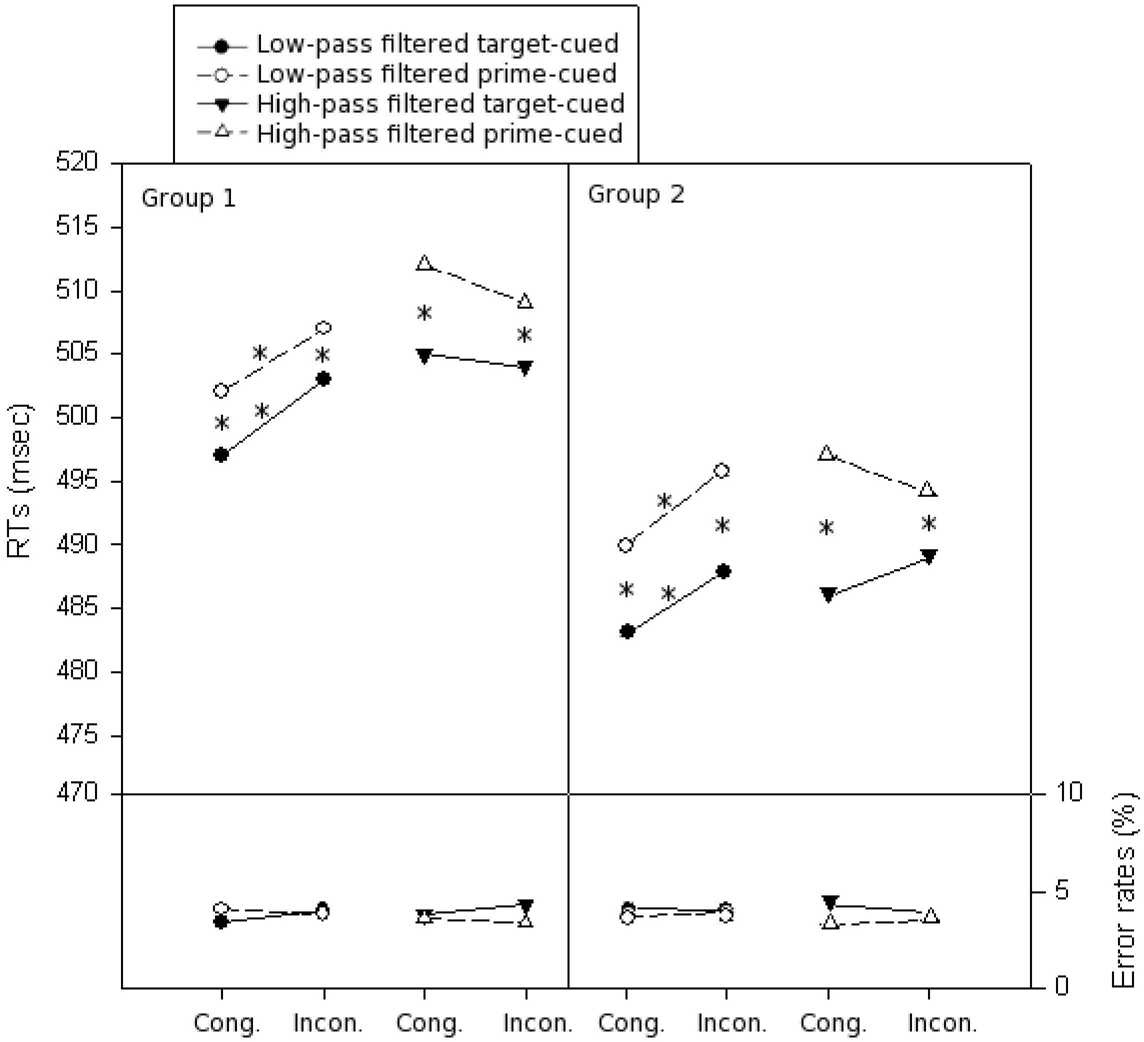

Figure 8: Mean Reaction Times (RTs) in milliseconds (upper panel) and error rates in percent (lower panel) on the y axis plotted as a function of congruence (congruent [Cong.] vs. incongruent [Incon.]), prime type (low-pass filtered [LSF], high-pass filtered [HSF]), cue type (target-cued vs. prime-cued) and Group (1: only target fixated HSF primes [left panel], 2: control group [right panel]) on the x axis, in Experiment 2 (circles = low-pass filtered [LSF] conditions; triangles = high-pass filtered [HSF] conditions; target-cued = solid lines and filled symbols; prime-cued = dashed lines and unfilled symbols). Congruence effects can be seen in the low-pass filtered target-cued and prime-cued conditions of both Groups 1 and 2, but not in the high-pass filtered conditions. Additional details of the mean RTs, error rates, and prime visibilities are summarized in Table 3. A star (*) shows the significant effects of congruence (when it appears in the middle of a line) or cue type (when two starts appear each between the starting and the ending points of lines).

Table 3. Proportion of trials included in each condition of Group 1 of Experiment 2, mean reaction times (RTs), error rates, and results of prime visibility tests for the conditions of Experiment 2. Mean RTs and error rates are compared in the congruent and incongruent conditions and the net congruence effect is calculated as the mean performance in the incongruent condition minus the mean performance in the congruent condition. Standard errors from the mean values are also provided. The results of *t*-tests against zero are given together with the mean *d'* values, averaged across congruent and incongruent conditions (Finkbeiner & Palermo, 2009). The degrees of freedom for all *t*-tests for the mean *d'*s in Group 1 and 2 were 29 and 39 respectively. The numbers in bold font indicate significant results. [Grp. = Group; LSF = Low-pass filtered; HSF = High-pass filtered; Congr. = Congruence; Cong. = Congruent; Incon. = Incongruent; Incl. = Included; Std. Err. = Standard Error; Sig. = Significance].

Conditions					**Reaction Times (ms)**			**Error rates (%)**			**Prime's visibility**			
Grp.	Primes	Cue-Type	Congr	Incl. Trials (%)	Mean RTs	Std. Err.	Net Congr.	Mean Error rates	Std. Err.	Net Congr.	Mean *d'* (Cong. & Incon.)	Std. Err.	*t*-test against 0	Sig. (2-tailed)
1	LSF	Target	Cong	73.0	497	8	**6**	3.4	0.7	0.6	-0.04	0.07	-0.55	.56
			Incon	70.7	503	9		4.0	0.8					
		Prime	Cong	68.4	502	9	**5**	4.1	0.6	-1.3	0.12	0.06	1.72	.10
			Incon	71.4	507	8		3.8	0.6					
	HSF	Target	Cong	71.7	505	9	-1	3.8	0.7	1.5	0.12	0.08	1.54	.14
			Incon	72.6	504	9		4.3	0.7					
		Prime	Cong	72.0	512	9	-3	3.6	0.7	-0.2	0.05	0.09	0.48	.68
			Incon	73.6	509	9		3.4	0.7					
2	LSF	Target	Cong		483	7	**5**	4.1	0.6	-0.1	0.07	0.06	1.30	.20
			Incon		488	8		4.0	0.7					
		Prime	Cong		490	8	**6**	3.7	0.5	0.2	-0.09	0.07	-1.32	.19
			Incon		496	7		3.9	0.6					
	HSF	Target	Cong		486	8	3	4.3	0.6	-0.4	0.07	0.07	1.03	.31
			Incon		489	8		3.9	0.6					
		Prime	Cong		497	8	-3	3.3	0.6	0.2	0.08	0.06	1.29	.20
			Incon		494	8		3.5	0.6					

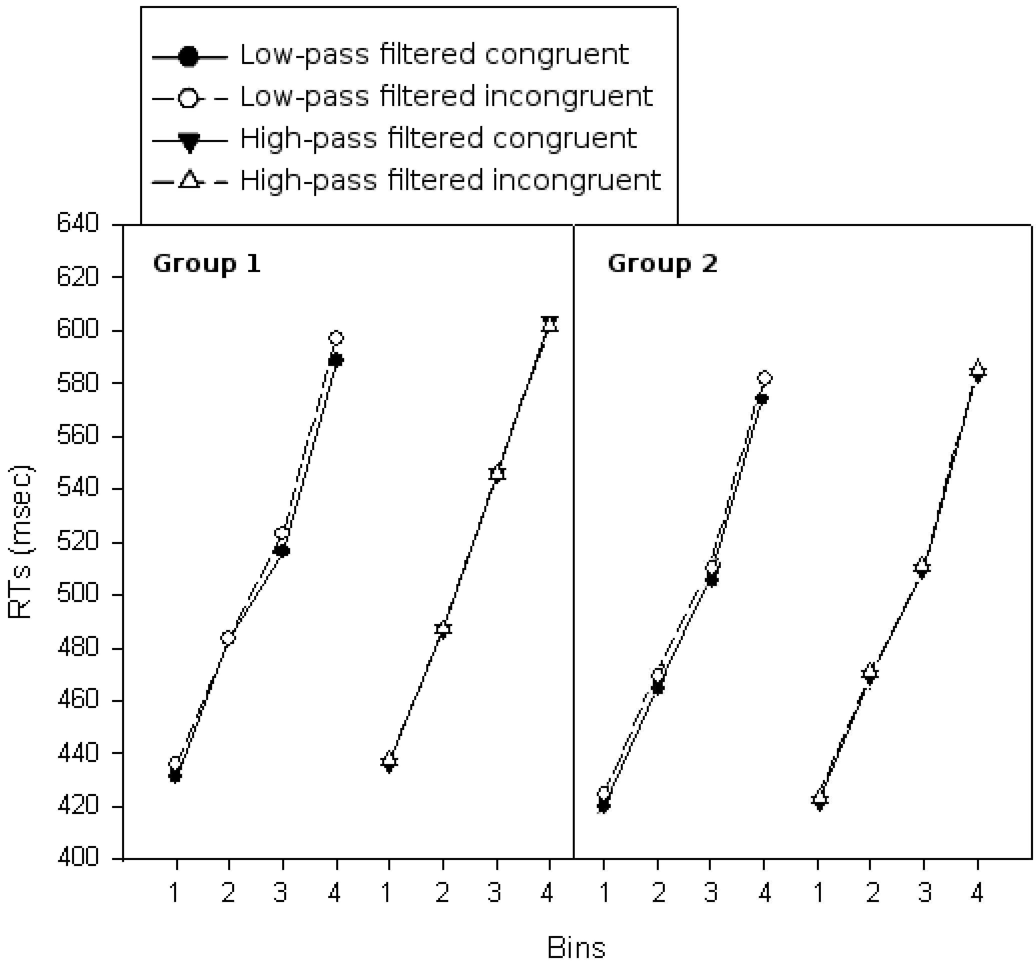

Figure 9: Mean Reaction Times (RTs) in milliseconds on the y axis plotted as a function of quartiles (1st to 4th bin of the RT distribution), prime type (low-pass filtered [LSF] vs. high-pass filtered [HSF]), and congruence (congruent vs. incongruent) on the x axis, in Group 1 (left panel) and Group 2 (right panel) of Experiment 2 (congruent = solid lines and filled symbols; incongruent = dashed lines and unfilled symbols; circles = unfiltered; triangles = high-pass filtered). Congruence effects were almost equal in all quartiles of the RT distribution in the LSF priming conditions of both Groups 1 and 2. Please note that the slight tendency towards a negative congruence effect in the HSF conditions of Group 1 (left panel's triangular symbols) was more prominent in the slowest responses (i.e., the 4th bin) but that this was not leading to a significant interaction of quartiles, congruence, and prime type.

Distribution analysis. As can be seen from Figure 9, the same conclusions were reached when we investigated the congruence effect as a function of the response speed. Like in Experiments 1, RTs were split into 4 quartiles (bins) and the same omnibus ANOVA was run with quartiles of the RT distribution (1, 2, 3, 4) as an additional within-participant variable. Apart from the above mentioned effects and interactions of our variables, we again did not find any other significant effect or interaction, all *F*s < 1.00.

Prime visibility. The participants were not aware of the sex of the masked primes in the HSF and LSF target-cued and prime-cued conditions. This can be seen in Table 3. *d'*s were calculated as in Experiments 1. *T*-tests against zero confirmed that *d'*s were not significantly different from zero in any of the target-cued and prime-cued LSF priming and HSF priming conditions of both Groups 1 and 2, all *p*s > .05. We additionally performed chi-square tests for the target-cued and prime-cued LSF priming and HSF priming conditions of both Groups 1 and 2. However, all of the results were non-significant, *p*s > .99, too.

Unmasked prime discrimination. The participants were able to successfully discriminate the sex of the prime faces in both unmasked HSF (M = 89.2%, SE = 1.4), $t(69) = 28.98$, $p < .001$, and unmasked LSF (M = 75.3%, SE = 2.0), $t(69) = 12.92$, $p < .001$, conditions. Moreover, the discrimination of the HSF primes was again significantly better than that of the LSF primes, $t(69) = 8.00$, $p < .001$.

Discussion

The results of Experiment 2 confirmed that only the masked peripheral LSF primes produced a congruence effect, and that this congruence effect was independent of whether the attention was shifted to the prime or target location. Peripheral masked HSF primes - though carefully equated for spectral power and contrast with the LSF primes - still failed to elicit any congruence effect. Also, if the masked HSF primes could be processed at all in the present paradigm, we were expecting a significant effect of the HSF primes when the attention was shifted to the prime location. However, no corresponding interaction was found. Our conclusions are also supported by the recorded fixation directions of the eyes: Masked primes were only rarely fixated and the assumed critical conditions for a failure of the HSF prime faces to produce a congruence effect were therefore met in all masked conditions. Moreover, again participants were unaware of the sex of the masked HSF and LSF primes.

To note, in Experiment 2, the masked HSF primes led to no congruence effect at all although their spectral power and contrast were similar to the LSF primes. Together the results confirmed that the unaware face-sex processing requires LSF face content, at least when the subliminal face is presented slightly to the periphery. Further, as in Experiment 1, the high discrimination rates of the HSF targets in the filler trials and that of the unmasked HSF primes in the control task at the end of the experiment confirmed that the participants comfortably discriminated the HSF prime face's sex even better than they discriminated the LSF prime face's sex (see de Gardelle and Kouider, 2010).

General Discussion

Unconscious vision (or even unaware processing in general) has long been regarded as governed by a single, unitary principle. For instance, Posner and Snyder's (1975) theory of automatic processing that regarded unconscious vision as being also attention-independent processing, or Weiskrantz et al.'s (1974) midbrain hypothesis that ascribed unconscious visual processing to the pathways from the SC to the cortex and conscious visual processing to cortical processing. These views are sometimes even jointly defended now a days (for an example, see Mulckhuyse & Theeuewes, 2010).

Recent research, however, has cast doubts on the classic views of unconscious vision, as we might call them. Authors have convincingly argued for an attention-dependence of even unconscious visual processing (Kiefer & Brendel, 2006; Naccache, Blandin, & Dehaene, 2002; Tapia, Breitmeyer, & Shooner, 2010) and for a cortical origin of unconscious visual processing (cf. Milner & Goodale, 1995; for an example from the area of face processing research, see Kouider et al., 2009). However, in over-emphasizing the generality of these findings, too, researchers might have thrown out the baby with the bathwater in denying the classical view altogether (Finkbeiner & Palermo, 2009). This was evident in the present research which successfully rehabilitated the classic view in one particular instance.

On the basis of the known selective sensitivity of the visual midbrain pathway to spatial LSF spectra of visual images and based on its assumed attention-independence, we have argued that some capacities, such as the human ability to discriminate the sex of a face without awareness, might well depend on processing along the SC in an attention-independent manner (cf. Deruelle & Fagot, 2005; Finkbeiner & Palermo, 2009; Goffaux et al., 2003; Johnson, 2005). In line with this classic view of automatic processing, we successfully demonstrated in the present research that (1) unaware face-sex processing was possible with LSF but not with HSF face images as primes, and (2) that unaware processing of a face's sex was independent of directing focal attention towards the visual stimuli. These results are jointly in line with the classic view of automatic processing and the midbrain hypothesis of unaware vision, and they additionally suggest that processing of the face primes in the aware mode relies on the parvo-cellular pathway with its known sensitivity to HSF visual content (cf. Merigan & Maunsell, 1993).

Concerning the small RT effect, (1) the stimuli presentation timing was correct as verified through the oscilloscope. (2) The mechanical feats associated with using a standard keyboard were also probably not the major reason for the size of the effect. It is true that a standard keyboard can compromise RT measurement. A typical problem would be a relatively large variance and a low temporal reliability of the measurement. Here, we minimized this factor by using a fast keyboard querying function ('*KbCheck*' of the Psychtoolbox). This function is keypress-oriented. On the current hardware, it only takes 1ms to query all keys of the keyboard in parallel. Further the standard keyboard had a sampling rate of 10kHz, this adds a little bit to the variance, but should not introduce a systematic bias and given the large number of responses the expected difference of means is completely negligible. Therefore the variance of the measurement is low but of course even this low variance would have distorted the small RT effects to some extent.

(3) The small size congruence effect is not unusual for masked face priming studies. For instance, the study by de Gardelle and Kouider (2010) was based on fame judgments about faces. For LSF primed famous faces, these authors found congruence effects of 6ms, 8ms, and 11ms (for prime durations of 43ms, 86ms, and 300ms, respectively). For unknown faces, significant congruence effects were 7ms and 8ms (for prime durations of 129ms and 300ms, respectively; cf. de Gardelle & Kouider, 2010). Similarly, in Experiment 3 of Finkbeiner and Palermo (2009) the congruence effects were 10ms, 9ms, and 8ms (for the 20ms, 60ms and 100ms SOAs respectively). (4) These congruence effects are comparatively smaller, however neuroscientific theories make few quantitative predictions about the smaller transmission times and timing differences between brain regions. For example, dynamics in theta and gamma frequency ranges can produce significant and systematic effects in the sub-millisecond range (Biederlack et al., 2006; Fries, Nikolić & Singer, 2007; König, Engel, Roelfsema, & Singer, 1995). Specifically the study of Biederlack et al. is important in this context, because it relates precise timing (of spikes) with perceptual effects. Furthermore, synaptic transmission times are 1ms and the brain is working on a millisecond time scale. For instance, König et al. (1995) have shown that the timing is precise down to fractions of milliseconds. Nikolić (2009) built on to these results and claimed that the relevant neuronal code makes use of that precision. Nikolić demonstrated that the sequence of firing on a sub-millisecond time scale allows efficient coding of stimulus properties. Moreover, Fries et al. (2007) have shown that timing relative to the cycle of gamma oscillations (which amounts to only a few milliseconds) is relevant for integrating top-down and bottom-up signals. Although there is currently no general theory to translate this to RTs, it is plausible that physiological network effects correspond to small perceptual timing effects and translate into small changes in RTs, too.

Based on the rationale of the classic view regarding face processing that we outlined above we would have predicted that in prime-cued conditions even the masked HSF primes should have created a congruence effect. This, however, was not found. We believe that some relatively marginal detail of our procedure could have led to the lack of a significant interaction. For example, it could be that the duration of the face primes and /or the cue-prime interval was just too brief to allow for a beneficial effect of attention on HSF-based congruence. It could also be that the primes were only rarely fixated. This was confirmed by Experiment 2. Maybe it is not attention but fixations that mediate whether cueing influences HSF priming. This would be in line with the fact that masked HSF primes influence target processing where they are fixated (cf. de Gardelle & Kouider, 2010). Whatever the exact reason: the lack of subliminal priming for HSF faces could not be due to insufficient sex information because these faces were classified into male and female categories just as reliably as LSF faces – but only when they were presented consciously.

We also want to emphasize that not all unaware face processing might be carried out along the midbrain pathway (cf. Kouider et al., 2009). For example, whereas a discrimination between the faces' sexes seems to draw on LSF content (cf. Schyns & Oliva, 1999), a fame judgment, as it was used in the study of de Gardelle and Kouider (2010), might equally rely on the HSF band. It is also possible that sensori-motor tasks as in the present study depend stronger on LSF content than perceptual tasks (as have been used by de Gardellle & Kouider, 2010). However, there is also accumulating evidence that at least unaware discrimination of facial emotional expression could also be carried out along the SC projection (cf. Hess, Reginald, Grammer, & Kleck, 2009; Laeng et al., 2010). Therefore, the degree to which the SC is involved during subliminal face processing might vary with the task. Jointly, the results might well be explained by the diagnostic-recognition framework (Schyns, 1998). It states that the particular task demands constrain which frequency bands are used to accomplish the task. The diagnostic-recognition framework is plausible because very similar top-down constraints also determine the fate of subliminal processing in many other conditions (cf. Ansorge & Neumann, 2005).

Above we reviewed prior research with subliminal emotional faces allowing alternative interpretations of subliminal processing in terms of salience differences between different emotional faces. This begs the question whether the sex discrimination task that was used in the present study truly overcame this problem. A major problem of past research with different emotional faces is their unequal salience. However, with respect to the sex of the faces no systematic confounding saliency difference is observed. Thus, any congruence effect based on faces' sexes cannot be due to saliency differences between the subliminal faces. However, HSF primes and LSF primes also differ with regard to their saliency. Could it thus be that this saliency difference rather than the filtering of particular frequencies of the faces was responsible for the absence of priming with HSF primes and its presence with LSF primes? We doubt that this could be a viable alternative explanation because if anything the HSF primes were more salient than the LSF primes and subliminal saliency effects are proportional to the saliency of the subliminal stimulus (e.g., Zhaoping, 2008). However, future studies could be devoted to directly test whether subliminal saliency could have an influence on top of frequency differences - that is whether saliency could boost the influence of the relevant frequencies of the masked faces.

On a more general note, the present findings are in line with the view that subcortical pathways in perceptual processing reflect phylogenetically relatively ancient adaptations to repeated evolutionary challenges. Researchers have repeatedly claimed that quick perceptual processing in an awareness-independent mode and along midbrain pathways could be typical of solving evolutionary pressing perceptual problems that granted survival, such as the efficient detection of emotional expressions in others (i.e., their faces), threat detection in re-occurring dangerous stimuli like snakes and spiders, and quick detection of the sex of the alter ego (LeDoux, 1996, 1998; Morris et al., 1999; Merigan & Maunsell, 1993; Öhman, 2002; Palermo & Rhodes, 2007). The results of the current study are in full agreement with this notion in that they showed that sex discrimination could indeed be brought about by a quick awareness-independent processing mode in a phylogenetically ancient pathway of the human brain. However, the magno-cellular pathway extends well into cortical areas. Therefore, it is possible that (part of the) subliminal LSF-based priming effects owe to cortical processes. Feedforward processing along cortical magno-cellular pathways has been claimed, for example, during object recognition (cf. Bar, 2003). The regions involved, such as dorsal prefrontal cortex, are different from the classical cortical face processing areas (e.g., Kanwisher & Yovel, 2009) but future research should also test the possibility that subliminal LSF face processing could (partly) depend on cortical pathways.

References

Ansorge, U., Horstmann, G., & Worschech, F. (2010). Attentional capture by masked color singletons. *Vision Research, 50,* 2015–2027.

Ansorge, U., & Neumann, O. (2005). Intentions determine the effects of invisible metacontrast-masked primes: Evidence for top-down contingencies in a peripheral cueing task. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 762-777.

Bar, M. (2003). A cortical mechanism for triggering top-down facilitation in visual object recognition. *Journal of Cognitive Neuroscience, 15*, 600-609.

Biederlack, J., Castelo-Branco, M., Neuenschwander, S., Wheeler, D. W., Singer, W., Nikolić, D. (2006). Brightness induction: rate enhancement and neuronal synchronization as complementary codes. *Neuron, 52(6),* 1073-1083.

Breitmeyer, B. G., & Ögmen, H. (2006). *Visual masking: Time slices through conscious and unconscious vision*. Oxford, UK: Oxford University Press.

Bridge, H., Thomas, O., Jbabdi, S., & Cowey, A. (2008). Changes in connectivity after visual cortical brain damage underlie altered visual function. *Brain, 131*, 1433-1443.

de Gardelle, V., & Kouider, S. (2010). How spatial frequencies and visual awareness interact during face processing. *Psychological Science*, *21*, 58-66.

de Gelder, B., Vroomen, J., Pourtois, G., & Weiskrantz, L. (1999). Non-conscious recognition of affect in the absence of striate cortex. *NeuroReport*, *10*, 3759–3763.

Deruelle, C., & Fagot, J. (2005). Categorizing facial identities, emotions, and genders: Attention to high- and low-spatial frequencies by children and adults. *Journal of Experimental Child Psychology, 90*, 172–184.

Dimberg, U., Thunberg, M., & Elmehed, K. (2000). Unconscious facial reactions to emotional facial expressions. *Psychological Science*, *11,* 86-89.

Dolan, R. J., Fletcher, P., Morris, J., Kapur, N., Deakin, J. F. W., & Frith, C. D. (1996). Neural activation during covert processing of positive emotional facial expressions. *NeuroImage, 4*, 194-200.

Finkbeiner, M., & Palermo, R. (2009). The role of spatial attention in nonconscious processing: A comparison of face and non-face stimuli. *Psychological Science*, *20,* 42–51.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 680–698.

Fries, P., Nikolić, D., & Singer, W. (2007). The gamma cycle. *Trends in Neurosciences, 7,* 309-316.

Goffaux, V., Jemel, B., Jacques, C., Rossion, B., & Schyns, P.G. (2003). ERP evidence for task modulation on face perceptual processing at different spatial scales. *Cognitive Science, 27,* 313–325.

Gonzalez, R. C., Woods, R. E., & Eddins, S. L. (2004). *Digital Image Processing Using MATLAB.* Prentice Hall, Upper Saddle River, NJ.

Graham, D. J., & Redies, C. (2010). Statistical regularities in art: Relations with visual coding and perception. *Vision Research, 50,* 1503–1509.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.

Hess, U., Reginald, B. A. Jr., Grammer, K., & Kleck, R. E. (2009). Face gender and emotion expression: Are angry women more like men? *Journal of Vision, 9(19),* 1-8.

Horstmann, G., Becker, S., Bergmann, S. & Burghaus, L. (2010). A reversal of the search asymmetry favoring negative schematic faces. *Visual Cognition*. *18*, 981-1016.

Itti, L., Koch, C., & Niebur, E. (1998). A model of saliency-based visual attention for rapid scene analysis. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 20(11),* 1254–1259.

Johnson, M. H. (2005). Subcortical face processing. *Nature Reviews Neuroscience*, *6*, 766–774.

Jolij, J., & Lamme, V. A. (2005). Repression of unconscious information by conscious processing: Evidence from affective blindsight induced by transcranial magnetic stimulation. *Proceedings of the National Academy of Sciences, 102,* 10747-10751.

Kammer, T. (2007). Masking visual stimuli by transcranial magnetic stimulation. *Psychological Research*, *71*, 659-666.

Kanwisher, N., & Yovel, G. (2009). The fusiform face area: A cortical region specified for the perception of faces. *Philosophical Transactions of the Royal Society B – Biological Sciences, 361*, 2109-2128.

Kiefer, M., & Brendel, D. (2006). Attentional modulation of unconscious 'automatic' processes: Evidence from event-related potentials in a masked priming paradigm. *Journal of Cognitive Neuroscience*, *18*, 184–198.

Kiss, M., & Eimer, M. (2008). ERPs reveal subliminal processing of fearful faces. *Psychophysiology, 45*, 318-326.

Koch, C., & Ullman, S. (1985). Shifts in selective visual-attention — towards the underlying neural circuitry. *Human Neurobiology, 4,* 219–227.

König, P., Engel, A. K., Roelfsema, P. R., & Singer, W. (1995). How precise is neuronal synchronization? *Neural Computation 7,* 469-485.

Kouider, S., Eger, E., Dolan, R. J., & Henson, R. N. (2009). Activity in face-responsible brain regions by invisible, attended faces: evidence from masked priming. *Cerebral Cortex*, *19*, 13–23.

Laeng, B., Profeti, I., Sæther, L., Adolfsdottir, S., Lundervold, A. J., Vangberg, T., Øvervoll, M., Johnsen, S. H., & Waterloo, K. (2010). Invisible expressions evoke core impressions. *Emotion*, *10*, 573-586.

LeDoux, J.E. (1996). *The emotional brain, Simon and Schuster, New York*.

LeDoux, J.E. (1998). Fear and the brain: Where we have been, and where are we going? *Biological Psychiatry*, *44,* 1229–1238.

Lee, S. E., Johansen-Berg, H., & Ptito. A. (2006). Unconscious vision: new insights into the neural correlate of blindsight using diffusion tactography. *Brain, 129*, 1822-1832.

Lundqvist, D., Flykt, A., & Öhman, A. (1998). *The Karolinska Directed Emotional Faces—KDEF* [CD ROM]. Stockholm: Karolinska Institutet, Department of Clinical Neuroscience, Psychology Section.

McCarthy, G., Puce, A., Gore, J. C., & Allison, T. (1997). Face-specific processing in human fusiform gyrus. *Journal of Cognitive Neuroscience, 9*, 605-610.

Merigan, W. H., & Maunsell, J. (1993). How parallel are the primate visual pathways? *Annual Review of Neuroscience, 16,* 369–402.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford: Oxford University Press.

Morris, J. S., Öhman, A., & Dolan, R. J. (1999). A subcortical pathway to the right amygdala mediating ‘unseen’ fear. *Proceedings of the National Academy of Science, 96*, 1680–1685.

Mulckhuyse, M., & Theeuwes, J. (2010). Unconscious orienting to exogenous cues: A review of the literature. *Acta Psychologica*, *143*, 199–209.

Naccache, L., Blandin, E., & Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science*, 416–424.

Nikolić, D. (2009). Model this! Seven empirical phenomena missing in the models of cortical oscillatory dynamics. *Proceedings of the International Joint Conference on Neural Networks, IJCNN 2009,* 2272-2279.

Norris, D., & Kinoshita, S. (2008). Perception as evidence accumulation and Bayesian inference: Insights from masked priming. *Journal of Experimental Psychology: General, 137,* 434–455.

Öhman, A. (2002). Automaticity and the amygdala: Nonconscious responses to emotional faces. *Current Directions in Psychological Science, 11,* 62–66.

Olshausen, B. A., & Field, D. J. (1996). Emergence of simple-cell receptive field properties by learning a sparse code for natural images. *Nature, 381*, 607-609.

Palermo, R., & Rhodes, G. (2007). Are you always on my mind? A review of how face perception and attention interact. *Neuropsychologia*, *45,* 75–92.

Pegna, A. J., Khateb, A. Lazeyras, F., & Seghier, M. L. (2005). Discriminating emotional faces without visual cortices involves the right amygdala. *Nature Neuroscience, 8*, 24-25.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition* (pp. 55-85). Hillsdale, NJ: Erlbaum.

Santos, A., Mier, D., Kirsch, P., & Meyer-Lindenberg, A. (2010). Evidence for a general face salience signal in human amygdala. *NeuroImage*, *54*, 3111-3116.

Schiller, P. H., Malpeli, J. G., & Schein, S. J. (1979). Composition of geniculo-striate input to superior colliculus of the rhesus monkey. *Journal of Neurophysiology*, *42*, 1124–1133.

Schyns, P. G. (1998). Diagnostic recognition: Task constraints, object information and their interactions. *Cognition*, *67*, 147–179.

Schyns, P. G., & Oliva, A. (1999). Dr. Angry and Mr. Smile: When categorization flexibly modifies the perception of faces in rapid visual presentations. *Cognition*, *69*, 243–265.

Tapia, E., Breitmeyer, B. G., & Shooner, C. R. (2010). Role of task-directed attention in nonconscious and conscious response priming by form and color. *Journal of Experimental Psychology: Human Perception and Performance*, *36*, 74-87.

Tamietto, M., & de Gelder, B. (2010). Neural basis of the non-conscious perception of emotional signal. *Nature Reviews Neuroscience, 11*, 697-709.

Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2003). Distinct spatial frequency sensitivities for processing faces and emotional expressions. *Nature Neuroscience*, *6*, 624–631.

Walther, D., & Koch, C. (2006), Modeling attention to salient proto-objects. *Neural Networks 19*, 1395-1407.

Weiskrantz, L. (1986). *Blindsight: A case study and implication.* Oxford: Oxford University Press.

Weiskrantz, L., Warrington, E.K., Sanders, M.D., & Marshall, J. (1974). Visual capacity in the hemianopic field following a restricted occipital ablation. *Brain*, *97*, 709–728.

Zhaoping, L. (2008). Attention capture by eye of origin singletons even without awareness – A hallmark of a bottom-up saliency map in the primary visual cortex. *Journal of Vision*, *8*, 1-18.

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Supported by, Deutsche Forschungsgemeinschaft Grant An 393/5-1 to Ulrich Ansorge, Werner Klotz, and Ingrid Scharlau, eSMC FP7-ICT-270212 eSMCs to Peter König, and an Australian Research Fellowship to Matthew Finkbeiner from the Australian Research Council (DP0880806). We are thankful to Daniel Graham and Jose Pablo Ossandon for the technical assistance during data analyses, and Julian Braehler, Christian Rammel, Bernadette Zecha, and Martin Kohl for help with the data collection.

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7. Space-Valence Priming with Subliminal and Supraliminal Words

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Journal Publication Citation:

Ansorge*, U., Khalid*, S., & König, P. (2013). Space-Valence Priming with Subliminal and Supraliminal Words. *Frontiers in Psychology,* 4:81. (DOI: 10.3389/fpsyg.2013.00081) [* = shared 1st Authorship]

Abstract

To date it is unclear whether (1) awareness-independent non-evaluative semantic processes influence affective semantics and whether (2) awareness-independent affective semantics influence non-evaluative semantic processing. In the current study, we investigated these questions with the help of subliminal (masked) primes and visible targets in a space-valence across-category congruence effect. In line with (1), we found that subliminal space prime words influenced valence classification of supraliminal target words (Experiment 1): Classifications were faster with a congruent prime (e.g., the prime 'up' before the target 'happy') than with an incongruent prime (e.g., the prime 'up' before the target 'sad'). In contrast to (2), no influence of subliminal valence primes on the classification of supraliminal space targets into up- and down-words was found (Experiment 2). Control conditions showed that standard masked response-priming effects were found with both subliminal prime types, and that an across-category congruence effect was also found with supraliminal valence primes and spatial target words. The final Experiment 3 confirmed that the across-category congruence effect indeed reflected priming of target categorization of a relevant meaning category. Together, the data jointly confirmed prediction (1) that awareness-independent non-evaluative semantic priming influences valence judgments.

Introduction

Human evaluation or appraisal processes concern the assignment of positive and negative valence to things and events (Arnold, 1960; Lazarus, 1968; Scherer, Schorr, & Johnston, 2001; Storbeck & Clore, 2007). Such appraisal processes are very important for human ontogenetic and phylogenetic fitness (Arnold, 1960; LeDoux, 1998). The appraisal of things and events is made with respect to an organism's vital goals. Appraisal can thus guide the selection of crucial stimulus information and goal-directed actions for utility maximization because utility is based on the achievement of merited or positively evaluated outcomes and the avoidance of negative consequences (Pessoa, Kastner, & Ungerleider, 2002; Posner & Dehaene, 1994). In fact, humans carry out evaluations so routinely and automatically (Kissler, Herbert, Peyk, & Junghöfer, 2007) that the corresponding appraisal processes can be triggered by irrelevant words, and even by stimuli remaining outside of the awareness of humans, such as subliminal or unconscious words or tokens (Galliard et al., 2006; Klauer, Eder, Greenwald, & Abrams, 2007; Naccache et al., 2005; Pessiglione et al., 2007). These studies suggest a fast evaluation system that operates independent of conscious perception.

Despite their enormous significance, however, to date we do not fully understand how such automatic evaluations relate to other non-evaluative dimensions of semantic processes. Here, we refer to semantic processes as the processes concerned with the assignment of meaning in general (Kintsch & Van Dijk, 1978; Meyer & Schvaneveldt, 1976; Osgood, Suci, & Tannenbaum, 1957; Rey, 2003). According to some theories, valence would be one integral dimension of all semantic meaning (Osgood et al., 1957). Even if this is true, however, it remains to be specified whether evaluative meaning is as quickly available as non-evaluative meaning or whether non-evaluative meaning precedes evaluative meaning. One possibility is that evaluations are special and carried out so quickly (LeDoux, 1998; Zajonc, 1980) as to precede and ground visual recognition and subsequent processing of non-evaluative forms of meaning. In line with this, for example, visual stimuli with a conditioned valence can elicit valence-dependent changes of visually evoked potentials of the human EEG with a latency of less than 100 ms (Stolarova, Keil, & Moratti, 2006). Related to this, Naccache et al. (2005), for example, demonstrated that visually masked subliminal words elicited valence-dependent activation of the human amygdala, a brain structure involved in emotional processing (LeDoux, 1998).

On the other hand, some emotion theories argued that visual recognition and specific non-evaluative semantic inferences have to precede appraisal and evaluative processes (Nummenmaa, Hyönä, & Calvo, 2010; Storbeck & Clore, 2007). Specifically, according to the embodied cognition view, word meaning is always grounded in more basic representations, such as sensory or sensorimotor representations (Barsalou, 1999, 2008; Glenberg & Kaschak, 2002; Zwaan, Stanfield, & Yaxley, 2002). Thus, valence could be accessible only after some other forms of non-evaluative sensory meaning have been successfully extracted from a word. In line with this, participants in a study of Nummenmaa et al. (2010), for example, were able to saccade towards one of two scenes based on a scene's semantic content before they were able to saccade to a scene based on a scene's valence or affective content. Likewise, Niedenthal (2007) argued that emotions could in general be grounded in preceding basic sensory, perceptual, and sensorimotor representations of postures and facial expressions. These divergent claims are the point of departure for the present research.

We address the directed interaction of valence evaluation, semantic processing and conscious perception. As follows from the above, a key issue is how quickly the valence of a word becomes available. Is valence accessible before non-evaluative forms of meaning, especially sensory-related semantic meaning? Or is the sensory-related and non-evaluative meaning of a word accessible before its valence? For our test, we used an across-category priming effect of sensory representations on valence recognition: the influence of spatial verticality on valence classification where spatially high corresponds to positive valence, and spatially low to negative valence. Of course, spatial location is but one of the sensory representations that nurtures the embodied representation of emotions. For instance, facial expressions are also among the powerful sensory representations that link up to emotions (Niedenthal, Winkielman, Mondillon, & Vermeulen, 2009). However, the association between valence and space is strong, robust, and already reflected in the very meaning of some words (Lakoff & Johnson, 1980; Melara & O'Brien, 1987). For example, the spatial word '*high*' can be used almost synonymously to denote an affective state of '*euphoria*' and the spatial word '*low*' for an affective state of '*depression*'. In their seminal experiments, Meier and Robinson (2004) demonstrated this modulating influence of spatial verticality on valence in a *space-valence congruence effect*: Their participants were faster when discriminating the valence of positive words above screen center and of negative words below screen center. This advantage in space-valence congruent conditions was found in comparison to incongruent conditions, in which the negative words were presented above screen center and the positive words below screen center (for related results, see Ansorge & Bohner, in press; Crawford, Margolies, Drake, & Murphy, 2006; Gozli, Chasteen, & Pratt, in press; Horstmann, 2010; Horstmann & Ansorge, 2011; Santiago, Ouellet, Román, & Valenzuela, 2012; Weger, Meier, Robinson, & Inhoff, 2007).

So far, this space-valence congruence effect has not been tested with subliminal words. This, however, is important. If we can demonstrate an across-category interaction, with subliminal words (Ansorge, Kiefer, Khalid, Grassl, & König, 2010; Forster, 1998) then the space-affect congruence interaction during lexical access reflects a form of early automatic impact of either quick semantic processes on evaluations or of quick evaluative appraisal on semantic processing. For example, Lamme (2003; Lamme & Roelfsema, 2000) estimated that unaware processing occurs during the first 100 ms post-stimulus. The exact duration might be slightly longer (Mulckhuyse & Theeuwes, 2010) but authors share the view that awareness-independent processing occurs early, during the feed-forward phase of stimulus processing, whereas awareness-dependent processing takes time and occurs later because it depends on feedback from processes higher up the hierarchy (Lamme, 2003). This implies limitations on subliminal processing. For example, subliminal processing could sometimes be conditional on top-down task sets. To be precise, subliminal processing could be 'conditionally automatic', meaning that it depends on the task-relevance of the unaware stimulus (e.g., of a semantic dimension of a subliminal word) (Bargh, 1992). Yet, importantly, this also means that a subliminal word does not elicit a fitting intention for its own processing in and by itself (Forster, 1998; Kinoshita, Mozer, & Forster, 2011). On the contrary, before the processing of subliminal stimuli can take place the prior set-up of a top-down or goal-directed intention would have to be firmly established (Klinger, Burton, & Pitts, 2000; Kunde, Kiesel, & Hoffmann, 2003). Only once such an intention, goal, or task set has been firmly established, a stimulus' meaning of which a person remains unaware would be able to elicit a stimulus processing in the feed-forward processing phase (e.g., Ansorge et al., 2010; Ansorge, Reynvoet, Hendler, Oettl, & Evert, in press; Norris & Kinoshita, 2008). Note that this general assumption also holds true for the processing of a subliminal word's valence meaning (De Houwer, Hermans, Rothermund, & Wentura, 2002; Eckstein & Perrig, 2007; Klauer & Musch, 2002; Klinger et al., 2000; see also Spruyt, De Houwer, & Hermans, 2009; Spruyt, De Houwer, Everaert, & Hermans, 2012).

Here, to test the predictions, and to understand whether sensory semantics quickly and (conditionally) automatically affected evaluations during the feed-forward phase and/or whether this is the other way round, we used (1) subliminal spatial words as primes and valence words as targets (Experiments 1 and 3), or we used (2) subliminal valence words as primes and spatial words as targets (Experiments 2 and 3). If valence meaning is based on (connotative) spatial representations, we expected a congruence effect of space primes on target evaluations (in Experiment 1). In the congruent condition, a valence judgment should be facilitated. For example, the prime word 'up' should facilitate classifying the emotional target 'happy' as positive. Facilitation was expected compared to the incongruent condition, for example, when the prime word 'down' was presented prior to the emotional target 'happy'. If the expected congruence effect reflected a quick, mandatory (or conditionally automatic) process, this space-valence congruence effect should be found with subliminal space primes, too (Ansorge et al., 2010). In addition, if word valence is as quickly available as a word's spatial meaning, we should find a congruence effect in the reversed situation (in Experiment 2) in which subliminal valence primes were presented before spatial targets.

When related predictions have been tested concerning the symmetry versus asymmetry of the space-valence congruence effect in the original paradigm of Meier and Robinson (2004), researchers observed congruence effects based on irrelevant spatial positions during word evaluation but no influence of irrelevant word valence on the discrimination of word locations (Santiago et al., 2012; but see Experiment 3 of Meier & Robinson, 2004). However, Santiago et al. achieved their results with clearly visible words and locations, leaving it open whether a similar asymmetry of space-valence congruence originates during the feed-forward phase of processing. In addition, when more attention was shifted to the irrelevant valence of the clearly visible words, the space-valence congruence effect was reestablished even during spatial discrimination (Experiment 6 of Santiago et al., 2012).

In our study, as control conditions, we therefore used (1) blocks with clearly visible, so-called 'supraliminal' primes and targets from different categories (and from the same categories) and (2) trials with subliminal primes and targets from the same category (e.g., a valence prime before a valence target) instead of primes and targets from different categories in both Experiments 1 and 2. In the control conditions, several hypotheses predict a congruence effect. With the supraliminal primes, a congruence effect could be based on strategic rather than (only) quick, obligatory (or conditionally automatic) processing of the visible prime because the longer perceptual trace of the visible primes affords also more attentional dwelling on visible than masked primes: The clearly visible prime will be seen and can elicit its strategic processing in and by itself, so that processing of the priming word would no longer be dependent on a preceding fitting task set (Cheesman & Merikle, 1985; Forster, 1998). For example, in the study of Cheesman and Merikle, participants strategically used the predictive power of the categories of the visible prime words of male and female gender names for the target-word categories of female and male gender names, respectively. This was evident in the efficient preparation of the most likely target-word responses. This strategic effect was found when the prime words were visible but not when the prime words were invisible (see also, e.g., Kinoshita et al., 2011). It is possible that this boosting influence of strategies on priming is due to a fundamental difference between feed-forward processing and recurrent processing: Due to the participants' awareness of the visible prime, this prime word might be broadcasted to different processing modules throughout the mental sphere and could thus be used for multiple new purposes, including the strategic assessment of the fit of its meaning relative to that of the target (Baars, 1988; Dehaene & Naccache, 2001). Therefore, the standard space-valence congruence effect should be found in the supraliminal conditions and a difference might be expected between supraliminal and subliminal conditions: If one of the prime word meaning dimensions (spatial or evaluative) contributing to the space-valence association is not also quickly and automatically processed (and thus could not be processed during the early feed-forward processing phase), then we expect that this dimension should become effective in the supraliminal but not in the subliminal conditions.

Also, in the second type of control conditions, with the subliminal primes of the same category, a congruence effect of the masked primes is predicted based on the prime's potential of priming a motor response (Ansorge & Neumann, 2005; Kunde et al., 2003; Neumann, 1990). Say, one needs to press the left button for a positive target word and a right button for a negative target. A positive prime before a positive target would then indicate giving the same response but a negative prime before a positive target would cause response conflict. Because this response-activation effect has already been demonstrated for subliminal prime words (Damian, 2001) – a principle termed "action triggering" (Kunde et al., 2003) –, at least in the within-category priming conditions a congruence effect should be found with the subliminal primes. In the subliminal conditions with primes and targets from the same category, we can expect a congruence effect, thus, making sure that our methods are sensitive enough to reveal a subliminal priming effect even if this priming effect happens to fail in the subliminal across-category (space-valence or valence-space) priming conditions.

To conclude, two origins of the congruence effects are conceivable in the present context: semantic priming (or category priming) – that is, decision priming in favour of one meaning or one category (Collins & Loftus, 1975; Plaut & Booth, 2000); and response priming (Klinger et al., 2000; Kunde et al., 2003). Semantic or category priming (Greenwald, Draine, & Abrams, 1996; Greenwald, Abrams, Naccache, & Dehaene, 2002; Kiefer, 2002; Martens, Ansorge, & Kiefer, 2011; Naccache & Dehaene, 2001; Norris & Kinoshita, 2008) was expected in the across-category priming conditions. Response priming (and maybe semantic or category priming) was expected in the within-category priming conditions only (Damian, 2001; Kunde et al., 2003).

Prior research has shown that the different origins of the congruence effect can be discriminated on the basis of their development over time [i.e., over the reaction time (RT) distribution]. According to Kinoshita and Hunt (2008), the priming of a decision for or against one category of semantically defined targets would be reflected in a temporally stable congruence effect. This congruence effect would be present in about similar strength across all of the RT distribution, from fast to slow responses. Thus, a congruence effect based on category priming should be found in fairly equal amounts for all RTs, from the fastest to the slowest.

By contrast, according to Kinoshita and Hunt (2008), a congruence effect based on response priming should decrease across time (i.e., across the RT distribution) in a manner different from a category-priming effect. A response priming effect should be stronger among the faster responses and it should decrease among the slower responses. To understand the origin of the expected congruence effects in the current study, we therefore tested the congruence effects as a function of the RT.

Experiment 1

In Experiment 1, our participants had to categorize the clearly visible valence targets as either positive (e.g., the target '*joyful*') or negative (e.g., the target '*sad*') in a 2 (within/across category) × 2 (congruent/incongruent) × 2 (visible/masked) design. They had to press one of two keys (left key vs. right key) to classify each target. Prior to every target, a prime word was shown. In half of the trials of the across-category priming condition, the prime was a spatial up-word (e.g., the word '*above*'), and in the other half it was a down-word (e.g., the word '*below*'). Together, these were the spatial priming conditions. In the within-category priming condition, in half of the trials the prime was a word of positive valence (e.g., the prime '*happy*'), and in the remaining trials it was of negative valence (e.g., the word '*frustrated*'). Together these were the valence priming conditions.

In the congruent conditions, primes and targets had associated meanings. For example, in the within-category condition a positive prime could have been presented before a positive target, while in the across-category condition an up-prime could have been presented before a positive target. In the incongruent conditions, primes and targets had less associated meanings. For example, in the within-category condition a negative prime could have been presented before a positive target, while in an across-category condition an up-prime could have been shown before a negative target.

In one block, the primes were presented as clearly visible words. In another block, the primes were presented subliminally, here: masked. In this context, masking denotes an experimental procedure where a visual stimulus replaces a preceding word so as to suppress the word's visibility (Marcel, 1983). To ensure that the masked primes were truly subliminal, prime visibility was individually tested, and participants that were suspiciously good during the discrimination of the masked primes were excluded.[1]

On the basis of prior research (Meier & Robinson, 2004), we expected an across-category, space-valence congruence effect with the visible primes. Responses should be faster in congruent than incongruent conditions. Critically, if sensory (here spatial) meaning can be extracted swiftly and (conditionally) automatically from the priming words, we might find a space-valence congruence effect in the visible *and* in the subliminal priming conditions – that is, regardless of awareness.

Method

***Participants*.** The participants of Experiment 1 and of the other experiments had normal or corrected-to-normal vision, were mostly university students and given course credit for participating. Two participants had to be excluded because of too high a number of correct prime-target judgments in the masked condition[1], and two further participants had to be excluded because of chance performance in the prime-target judgments of the unmasked condition, indicating that they were unable or unwilling to discriminate the unmasked prime-target relations. The remaining 40 participants (31 female, M_{age} = 22.0 years, age range: 18–28 years) were analyzed.

***Apparatus, stimuli, and procedure*.** Prime and target stimuli were German words denoting emotional adjectives or prime stimuli were spatial words denoting directions or positions on the vertical axis. We used the following prime and targets that were all high frequency words because there were more than 60 instances in 1 million words (Jescheniak and Levelt, 1994), with frequencies word counts in parentheses according to the Wortschatz Lexikon of the University of Leipzig, http://dict.uni-leipzig.de/, and frequencies calculated relative to 400.000 entries, contained in the Wortschatz Lexikon on the date of retrieval, December 5th, 2012). As positive valence word, we used: '*lustig*' (*jolly*) (2,521), '*glücklich*' (*lucky*) (6,097), '*freudig*' (*cheerful*) (558), '*vergnügt*' (*happy*) (483), '*spaßig*' (*funny*) (129), '*mutig*' (*brave*) (1,328), '*stolz*' (*proud*) (4,315), '*verliebt*' (*loving*) (2,300), '*fröhlich*' (*merry*) (1,862), and '*froh*' (*joyful*) (5,424), with a mean word length of Ø = 6.5 letters (range 4 – 9 letters) and an average frequency of Ø = 2,502. We used the following negative valence prime and target words: '*furchtsam*' (*fearful*) (59), '*ängstlich*' (*anxious*) (775), '*bekümmert*' (*worried*) (154), '*traurig*' (*sad*) (2,646), '*zornig*' (*furious*) (447), '*hasserfüllt*'[2] (*full of hate*) (339), '*wütend*' (*enraged*) (1,549), '*frustriert*' (*frustrated*) (899), '*beschämt*' (*ashamed*) (202), and '*schuldig*' (guilty) (4,753), with a mean word length of Ø = 8.3 letters (range 6 – 11 letters) and an average frequency of Ø = 1,182. The spatial primes that we used as up-words were: '*oben*' (*on top*) (21,453), '*darüber*' (*above*) (45,943), '*hinauf*' (2,214), '*aufwärts*' (1,652), '*empor*' (*upward*) (714), '*hoch*' (*high*) (27,559), '*gehoben*' (1,555), '*erhöht*' (*elevated*) (14,891), '*aufsteigend*' (143), '*steigend*' (*rising*) (750), with a mean word length of Ø = 6.6 letters (range 4 – 11 letters) and an average frequency of Ø = 11,687. Finally, the spatial primes that we used as down-words were: '*unten*' (*down*) (11,971), '*darunter*' (*below*) (22,589), '*hinab*' (1,024), '*abwärts*' (767), '*herab*' (*downward*) (1,624), '*niedrig*' (*low*) (3,529), '*gesenkt*' (*lowered*) (5,027), '*abfallend*'[2] (143), '*sinkend*' ('*declining*') (60), and '*tief*' (*deep*) (10,331) , with a mean word length of Ø = 6.3 letters (range 4 – 9 letters) and an average frequency of Ø = 5,707. These words were selected because of their relatively similar distributions in text corpora, a relatively similar length, and on the basis of their easy and equal discriminability of category membership (which was empirically tested during pre-testing).

Each of the twenty valence words was presented as a target equally often. For the creation of the within-category priming condition, each target was randomly combined with each of the nine remaining valence words. For the across-category priming condition, each of the valence targets was randomly combined with each of the ten spatial words as a prime. Across trials, the different prime words were equally likely and the resulting prime-target pairs were equally likely to be congruent or incongruent. In a trial, prime and target were never identical even in congruent conditions. This was done to rule out repetition priming (Forster, 1998).

All stimuli were presented in black (< 1 cd/m^2) on a gray background (24 cd/m^2). Each trial started with the presentation of a fixation cross centered on the screen for 750 ms (see Figure 1). In masked trials, a forward mask was shown next for 200 ms. It consisted of 10 randomly drawn uppercase letters. The prime word was shown for 34 ms immediately after the forward mask or after the blank screen in the case of visible trials. The prime was depicted in lowercase letters. In masked trials, the prime preceded a backward mask. The backward mask also consisted of 10 randomly drawn capital letters that were shown for 34 ms. In visible trials, both forward and backward masks were omitted and the masking screens were replaced by blank screens. Next, the target word was shown for 200 ms. In masked trials, all words and the masks were shown centered on the screen directly one after the other. Timing of all stimuli was adapted from prior studies that exhibited little prime visibility in masked and good prime visibility in unmasked conditions (Ansorge et al., 2010; Ansorge et al., 2011; Kiefer & Brendel, 2006).

The experiment consisted of two blocked conditions, one block with masked primes, and a second block with unmasked primes. The order of the blocks was either masked block before unmasked block, or vice versa, with different block orders balanced across participants. Each block lasted about 30 minutes. In each trial of both the masked and the unmasked conditions, participants had two tasks, first a blocked target-response task and subsequently a blocked prime-discrimination task. During the target-response task, participants discriminated the meaning of the target word. Half of the participants pressed the right key for positive target words and the left key for negative target words. The other half of the participants pressed the left key for positive targets and the right key for negative targets. The second task was a prime-visibility task. This task required that one key (say the right key) be pressed in trials, in which the prime was congruent to the target and the other key (say the left key) if the prime was incongruent to the target. The levels of the variable prime-target congruence that had to be judged were carefully explained to the participants with relevant examples in the instructions. This task was conducted in every trial, directly after the target-discrimination task, so that conditions in this task were exactly the same as in the target-response task. This task of discriminating between congruent and incongruent trials has two advantages as compared to a task of discriminating the prime's meaning (e.g., its valence) alone. First, the task of discriminating congruent from incongruent trials requires processing of prime *and* target. It thus necessitates processing of the targets not only in the target-discrimination task but also in the prime-visibility test. Because we are interested in understanding whether prime visibility in the target-discrimination task might account for any priming effect in these conditions, the congruence-incongruence discrimination task is thus more apt to answer the research question that we asked. Second and related, the congruence effect in the target-discrimination task can only be explained on the basis of supraliminal word processing if the critical characteristics of the corresponding conditions that created the priming effect can be correctly discriminated by the participants. This critical characteristic that is decisive for the priming effect – that is, whether a quick or a slow response can be given, is whether a trial is congruent or whether it is incongruent. Therefore, a fitting prime-visibility test needs to assess the participants' awareness of this critical difference rather than the participants' awareness of a difference between the primes that is only related to this critical difference, such as the exact meaning of the prime word alone. In the prime-visibility task, mappings of judgments to alternative (left and right) key presses were also fixed and balanced across participants.

After each incorrect response to the target and if the target-discrimination RT exceeded 1,250 ms, participants received feedback about their error or their too slow responses. Feedback took 750 ms. Thus, keeping a high accuracy and a fast response was mildly rewarded (i.e., saved 750 ms per trial). No feedback was given concerning the prime-visibility task.

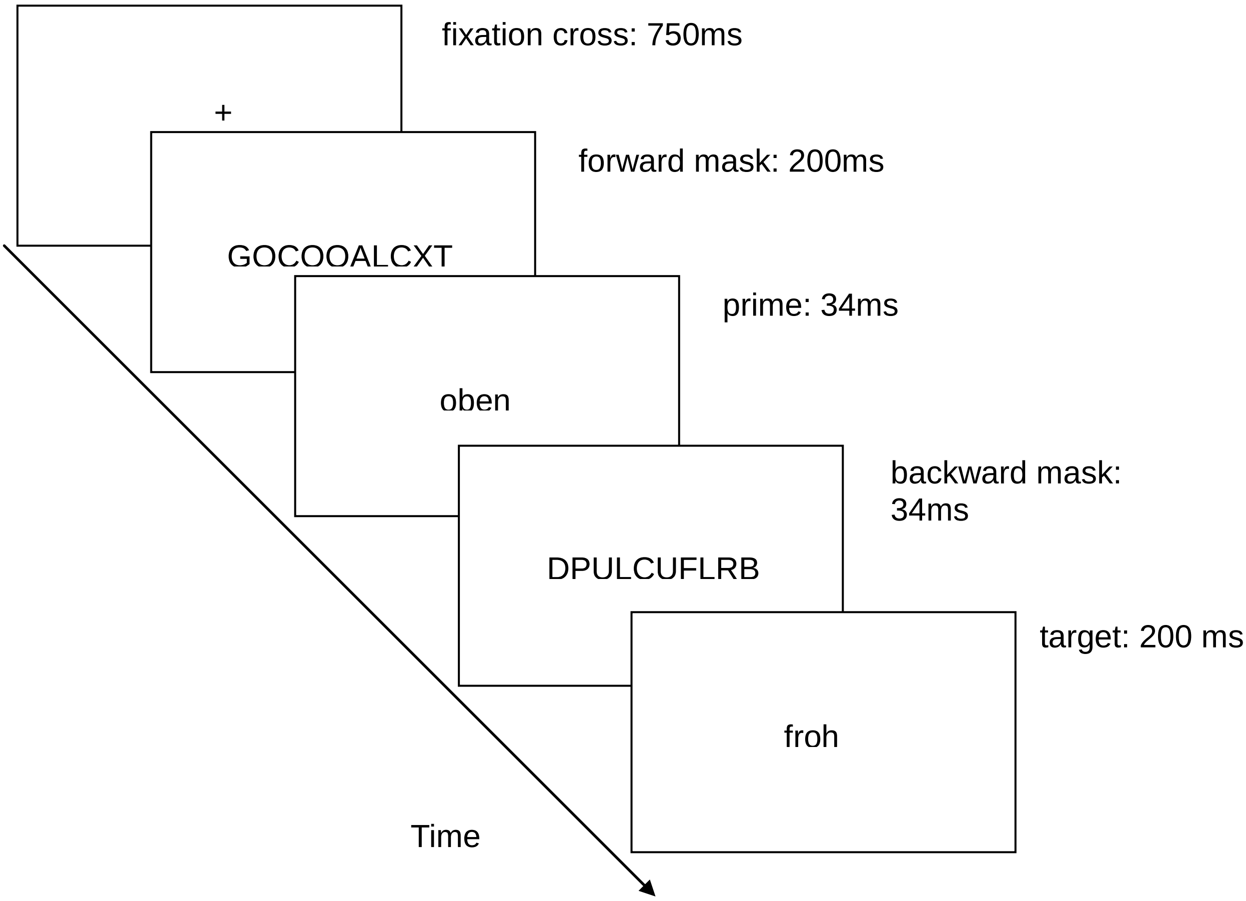

Figure 1: Depicted is an example of a congruent trial where a spatial up prime, here: 'oben' (on top), preceded a positive valence target, here:'froh' (joyful). The arrow depicts the direction of time. In the target-response blocks, participants had to categorize the targets. Only in the blocked prime-visibility task at the end of each half of the experiment, the participants also had to additionally judge prime-target congruence. Stimuli are not drawn to scale.

Each block consisted of 240 trials. In total (across blocks), this involved 60 trials of each combination of the 2 prime types (spatial primes; valence primes) × 2 prime-target congruence relations (congruent; incongruent). Prior to the first block, participants were carefully instructed about the target-response task and the prime-discrimination task. Also, prior to both blocks, the participants practiced the task for a minimum of 20 trials but they could also practice for another 20 trials if they wanted to practice more. During these practice phases, the procedure was explained verbatim in addition to the preceding written instructions, and in more detail if necessary (i.e., if there were questions).

Results

Of all correct responses, 3.8% were excluded because these RTs deviated by more than 2 SDs from a respective condition's and individual participant's mean RT (with SD and mean RT computed separately for each of the conditions and individuals).

An ANOVA of the medians of the correct responses, with the within-participant variables congruence (congruent; incongruent), prime type (valence; spatial), visibility (masked; unmasked), and quintile of RT distribution (1^{st} to 5^{th} quintile) led to the following results. Here and in the subsequent analyses, results were adjusted by Greenhouse-Geisser coefficients and the ε values are reported, if Mauchly tests indicated a deviation from sphericity.

A significant main effect of congruence, $F(1, 39) = 83.81$, $p < .01$, partial $\eta^2 = 0.68$, was found, reflecting faster RTs in congruent (652 ms) than incongruent (669 ms) conditions. There was also a significant main effect of prime type, $F(1, 39) = 14.35$, $p < .01$, partial $\eta^2 = 0.27$, indicating that responses after spatial primes were slightly faster (RT = 656 ms) than with valence primes (RT = 664 ms). Critically, we also found significant interactions between congruence and prime type, $F(1, 39) = 13.93$, $p < .01$, partial $\eta^2 = 0.26$, and between congruence and prime visibility, $F(1, 39) = 10.15$, $p < .01$, partial $\eta^2 = 0.21$.

Splitting up the data during follow-up ANOVAs, we confirmed a congruence effect with both types of primes, a strong across-category priming effect of the spatial primes, $F(1, 39) = 81.07$, $p < .01$, partial $\eta^2 = 0.68$ (congruent RT = 644 ms; incongruent RT = 669 ms), and a smaller within-category priming effect of the valence primes, $F(1, 39) = 7.83$, $p < .01$, partial $\eta^2 = 0.17$ (congruent RT = 660 ms; incongruent RT = 668 ms). Follow-up ANOVAs split up for visible and masked primes confirmed a stronger congruence effect with visible primes, $F(1, 39) = 76.10$, $p < .01$, partial $\eta^2 = 0.66$ (congruent RT = 650 ms; incongruent RT = 673 ms), than with masked primes, $F(1, 39) = 16.63$, $p < .01$, partial $\eta^2 = 0.30$ (congruent RT = 653 ms; incongruent RT = 664 ms).

There was also a trivial main effect of the variable quintile, $F(4, 156) = 270.59$, $p < .01$, partial $\eta^2 = 0.87$ (ε = 0.26), and the variable quintile also interacted significantly with congruence, $F(4, 156) = 6.97$, $p < .01$, partial $\eta^2 = 0.15$ (ε = 0.51), with prime type, $F(4, 156) = 5.80$, $p < .01$, partial $\eta^2 = 0.13$ (ε = 0.45), and in a marginally significant three-way interaction with congruence *and* prime type, $F(4, 156) = 3.02$, $p = .07$, partial $\eta^2 = 0.07$ (ε = 0.38). As it can be seen in Figure 2, the within-category congruence effect (incongruent RT – congruent RT) of the valence primes (depicted as circles) decreased across RTs. It was significant only in the faster RTs [1^{st} quintile: 22 ms, $t(39) = 5.96$, $p < .01$, 2^{nd} quintile: 15 ms, $t(39) = 4.43$, $p < .01$, 3^{rd} quintile: 12 ms, $t(39) = 3.61$, $p < .01$] but it was absent among the slower response (4^{th} quintile: 0 ms, 5^{th} quintile: -5 ms, both *t*s < 1.00). By contrast, the across-category congruence effect of the spatial primes (depicted as crosses in Figure 2) was fairly stable across RT. Across the RT distribution the congruence effect varied slightly in size between 20 ms and 30 ms (all *t*s > 2.70, all *p*s < .01). Together, these results are perfectly in line with the assumption that response activation was responsible for (within-category) valence-priming effects but categorization lay aground of spatial (across-category) priming because the valence prime were also response-relevant but the spatial primes were not. See also Figure 2 for the results.

An ANOVA of the ERs with the variables congruence, prime type, and visibility confirmed the picture. The slower median correct reactions in incongruent than congruent conditions were accompanied by a lower mean accuracy in incongruent (ER = 6.5%) than congruent (ER = 5.3%) conditions. This was reflected in a significant main effect of congruence, $F(1, 39) = 7.75$, $p < .01$, partial $\eta^2 = 0.17$. There was also a significant main effect of prime type $F(1, 39) = 17.77$, $p < .01$, partial $\eta^2 = 0.31$ – with higher ERs for valence (6.6%) than spatial primes (5.2%), and a significant interaction between congruence and prime type, $F(1, 39) = 20.62$, $p < .01$, partial $\eta^2 = 0.35$. Follow-up ANOVAs split up for the type of prime confirmed the existence of a significant main effect of congruence (3.4%) for spatial primes, $F(1, 39) = 34.11$, $p < .01$, partial $\eta^2 = 0.47$, but not for valence primes (-0.7%, $F < 1.00$).

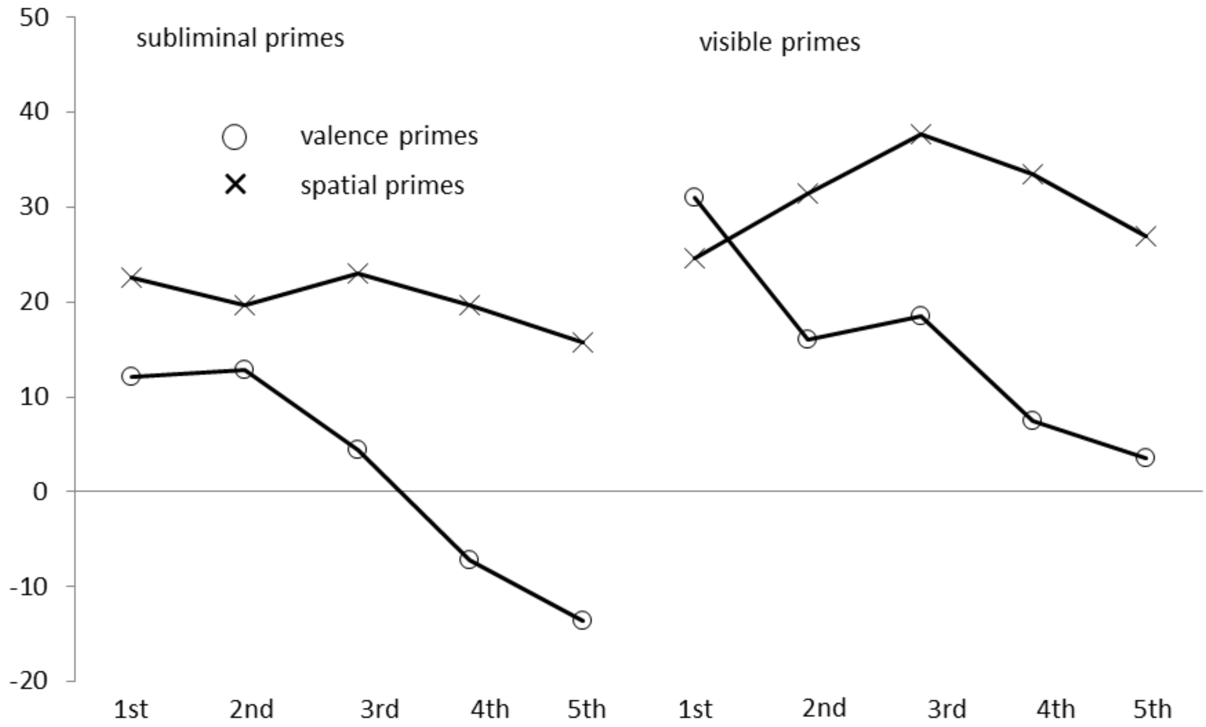

Figure 2: Mean congruence effects in Milliseconds, calculated as mean correct Reaction Times (RTs in ms) of incongruent conditions minus mean correct RTs of congruent conditions in Experiment 1, as a function of prime type (circles: valence primes; crosses: spatial primes), prime visibility (left side: subliminal primes; right side: visible primes) and quintile (1st to 5th) of the RT distribution on the x axis.

Supplementary information concerning polarity-correspondence effects. We also made sure that the within-category congruence effect did not merely reflect a polarity-correspondence effect (Lakens, 2012).[3] According to this interpretation, as compared to the so-called 'minus poles' (or '–poles') of a meaning dimension (e.g., negative concepts in the valence dimension and down concepts in the spatial dimension), the so-called 'plus poles' (or '+poles') of meaning dimensions (e.g., positive concepts and up concepts) are processed faster and additionally facilitate +pole responses. The polarity-correspondence hypothesis would thus predict that prime-target combinations of concepts with similar polarities (e.g., +/+ prime-target combinations) are facilitate as compared to combinations with dissimilar polarities, (e.g.,–/+ prime-target combinations). Although this is true of the –pole concepts, too, the slower –pole processing and responses should lead to reduced congruence effects, with a congruent but very slow –/– prime-target combination being not so different of an incongruent but slightly facilitated +/– prime-target combinations. As can be seen in Table 1 though, there was the expected facilitation for +targets but no strong difference between the congruence effects of +targets versus –targets.

Table 1. Reaction Times (in ms) as a function of prime-target combination in Experiment 1 and 2.

	Experiment 1	**Experiment 2**
+/+ prime-target	634 ms	617 ms
–/– prime-target	655 ms	623 ms
–/+ prime-target	645 ms	643 ms
+/– prime-target	679 ms	649 ms

Prime visibility tests. To test whether participants consciously identified the unmasked primes but failed to see the masked primes, we computed *d'*, a sensitive index of stimulus visibility (Reingold & Merikle, 1988). Individual *d'* was computed separately for masked and unmasked primes and for spatial primes and valence primes. For our measure of *d'* congruent trials counted as signals and incongruent trials as noise. Accordingly correct (i.e., 'congruent') judgments in congruent trials figured as hits, and incorrect (i.e., 'congruent') judgments in incongruent trials as false alarms (FAs).

The participants were not able to discriminate the masked prime-target relations with better than chance accuracy. For the masked spatial primes, *d'* was -0.10, $t(39) = 1.08$, $p = .29$, and for the masked valence primes it was 0.19, $t(39) = 1.70$, $p = .10$. In addition, the correlation between individual *d'* values and individual Cohen's *D* indices of congruence effects [calculated as (incongruent RT – congruent RT)/SD (pooled over congruent and incongruent) RT] indicated that there was no significant influence of residual prime visibility on the RT congruence effect for masked spatial primes, $r(40) = .003$, $p = .99$, and for masked valence primes, $r(40) = .03$, $p = .86$. The unmasked prime-target relations were successfully discriminated for the spatial primes, with *d'* = 2.34, $t(39) = 14.77$, $p < .01$, and the valence primes with *d'* = 2.82, $t(39) = 15.26$, $p < .01$.

Discussion

In line with a quick influence of sense-related word meaning, an across-category space-valence congruence effect was found even with masked spatial primes.[4] This across-category congruence effect was created by subliminal words because the masked primes could not be seen by the participants. The effect is in line with the predictions of the embodied cognition view that assumes that a swift and (conditionally) automatic extraction of sensory meaning from a word could occur so fast as to influence emotions and evaluations (Niedenthal, 2007). The effect is also in line with the observed fast and automatic extraction of non-evaluative meaning before stimulus evaluation (Nummenmaa et al., 2010). In line with these observations, the participants' processing of the spatial primes was so fast and efficient that an awareness of the primes was not a necessary precondition of the across-category congruence effect (Lamme, 2003).

The present experiment's across-category priming effect of spatial words on valence discriminations might appear surprising in light of the finding of Meier and Robinson (2004) that discriminating between the spatially upper or lower position of a string of crosses on the computer screen had no influence on the discrimination of the valence of a subsequent word in the center of the screen: Whether the discriminated position was congruent to a word's valence or not had no systematic influence on valence discrimination in Meier and Robinson's Experiment 3. However, Meier and Robinson asked their participants to respond first to the cross positions and only then to the valence targets whereas we asked our participants to first quickly respond to the valence targets. The use of the prime and the target in different tasks can be critical for the across-category congruence effect. For example, according to an explanation developed by Gozli et al. (in press), sorting prime and target into different tasks is one precondition that can lead to a reverted word-location congruence effect with short SOAs but not with long SOAs. Assuming that different reaction times to the spatial primes in Experiment 3 of Meier and Robinson led to a mixture of short and long prime-target intervals, it could thus be that their lacking congruence effect reflected a mixture of straight and reverted congruence effect that averaged to zero. Whereas Meier and Robinson thus clearly sorted the cross positions and valence targets into separate tasks and created different prime-target intervals, we used a single task of discriminating a word's valence and used a fix prime-target interval. Thus conditions for a straight across-category congruence effect were better in the current experiment than in Experiment 3 of Meier and Robinson.

Against our findings in Experiment 1, one might want to argue that the spatial primes were just implied by the set of task-relevant affective target words. According to this argument, the task of the participants to discriminate valenced emotional words, such as 'sad' and 'happy', would have led the participants to also judge spatial words, such as 'above' and 'below', by their respective connotative valence. In general agreement with this hypothesis, participants judge words, such as 'up' as more positive, and words such as 'down' as more negative (e.g., Eder & Rothermund, 2008). Although this alternative explanation is a theoretical possibility it would be difficult to reconcile this alternative explanation with the obvious differences between the congruence effects of the emotional primes and the spatial primes in the current study. Whereas the emotional primes led to a congruence effect that decreased across the RT distribution, this was not the case for the spatial primes. Therefore, the across-category congruence effect of the spatial primes was probably due to the priming of the target's categorization. This was reflected in the development of the across-category congruence effect over time. The RT distribution reflected a fairly stable congruence effect of the spatial primes. According to Kinoshita and Hunt (2008) this would be typical of a category-priming effect. In addition, the spatial words were also response-irrelevant in the first place because these words were not used as response-relevant targets anyway.

We also observed a weaker within-category congruence effect of the valence primes. This within-category priming effect probably reflected response activation. To note, the valence words were used as primes and targets. Therefore, the valence primes were response relevant. In line with this interpretation, the congruence effect of the valence primes decreased over RTs. It was stronger among the faster than the slower responses. This is typical of the response-activation effects of masked primes (Ansorge et al., 2010; Kinoshita & Hunt, 2008).

Finally, a significantly stronger congruence effect was found for visible than masked primes. The stronger influence of the visible primes probably reflected that their perceptual traces lingered longer and opportunities for attentional dwelling were thus higher with visible primes than masked primes. In line with this interpretation, when Santiago et al. (2012) directed their participants' attention to the task-irrelevant valence meaning of words, they found a significant space-valence congruence effect that was absent when attention was not directed towards word valence.

Experiment 2

Experiment 2 was our second test of the across-category priming effect. Some evidence suggests that the semantic content from images is extracted before an image can be evaluated (Nummenmaa et al., 2010). According to this line of thinking, the quick awareness-independent across-category congruence effect could be abolished when the roles of valence words and spatial words as primes and targets are reversed (as compared to Experiment 1).

We therefore reversed the roles of valence words and spatial words as across-category primes and targets. In contrast to Experiment 1, spatial words were now used as visible targets. The participants had to discriminate between up targets and down targets. As in Experiment 1, valence words as well as spatial words were used as primes. In this way, we were able to test whether masked valence primes created an automatic across-category space-valence congruence effect as would be predicted by a quick and automatic valence assessment of the words.

Method

Participants. Four participants had to be excluded based on their above-chance discrimination of the masked primes[1], and one because of very low performance even in the unmasked condition. The remaining 39 participants (29 female, M_{age} = 26.3 years, age range: 19–42 years) were analyzed.

Apparatus, stimuli, and procedure. These were the same as in Experiment 1, except for the changed targets and instructions. In Experiment 2, the participants were presented with space targets and they had to discriminate between up and down targets in the target-response task. Half of the participants responded to up targets by a right-hand key press and to down targets by a left-hand key press. The other half of the participants got the opposite mapping.

Results

Target-response task. See also Figure 3. Of all correct responses, 4.0% were discarded by the same criterion as was used in Experiment 1. We ran an ANOVA of the correct RTs with the within-participant variables congruence, prime type, prime visibility, and quintiles. This ANOVA confirmed the significant main effects of congruence, $F(1, 38) = 90.87$, $p < .01$, partial $\eta^2 = 0.71$, and an almost significant effect of prime type, $F(1, 38) = 3.79$, $p = .06$, partial $\eta^2 = 0.09$, as well as the important interactions between (1) congruence and prime type, $F(1, 38) = 23.21$, $p < .01$, partial $\eta^2 = 0.38$, (2) congruence and prime visibility, $F(1, 38) = 5.34$, $p < .05$, partial $\eta^2 = 0.12$, and (3) congruence, prime type, and prime visibility, $F(1, 38) = 4.62$, $p < .05$, partial $\eta^2 = 0.11$. Splitting up the data for follow-up analyses for different combinations of the steps of the variables congruence, visibility, and prime type (while collapsing across quintiles), we found significant congruence effects (incongruent RT – congruent RT) only for visible primes of either type, across-category valence primes (18 ms, $t[38] = 6.25$, $p < .01$) and within-category space primes (30 ms, $t[38] = 6.63$, $p < .01$), as well as for masked within-category space primes (26 ms, $t[38] = 7.72$, $p < .01$). However, there was no significant congruence effect with the masked across-category valence primes (4 ms, $t[38] = 1.17$, $p = .25$).

Crucially, and in line with different origins of the congruence effects in the different prime-type conditions, the ANOVA also revealed significant two-way interactions between quintile and congruence, $F(4, 152) = 5.39$, $p < .01$, partial $\eta^2 = 0.12$, and between quintile and prime type, $F(4, 152) = 6.26$, $p < .01$, partial $\eta^2 = 0.14$, as well as a significant three-way interaction between quintile, congruence, and prime type, $F(4, 152) = 6.61$, $p < .01$, partial $\eta^2 = 0.15$. Figure 3 depicts these results. As it can be seen by looking at the cross symbols (depicting the spatial primes), in line with a motor priming effect of the spatial primes their congruence effect now decreased over RTs. In the spatial priming conditions, congruence effects were 37 ms, 34 ms, 30 ms, 25 ms, and 12 ms, all $ts(38) > 2.20$, all $ps < .05$, from the 1st to the 5th quintile, respectively. By contrast, looking at the circular symbols (depicting the valence primes), especially in the visible conditions, in line with a category priming effect, congruence effects of the visible valence primes were relatively similar over RTs. From the 1st to the 5th quintile the across-category valence priming effect fluctuated between 9 and 12 ms, all $ts(38) > 2.20$, all $ps < .05$.

Figure 3 also indicates that a four-way interaction between congruence, prime type, visibility, and quintile should have obtained – basically because the absence of the congruence effect with masked valence primes only –, but this interaction fell short of significance, $F(4, 152) = 2.10$, $p = .08$, partial $\eta^2 = 0.05$.

In addition we observed an interaction between quintile and prime visibility, $F(4, 152) = 2.89$, $p = .07$, reflecting a shallower slope (i.e., less variance) of the RT distribution in masked than in visible conditions, as well as a trivial main effect of quintile, $F(4, 152) = 853.30$, $p < .01$, partial $\eta^2 = 0.96$.

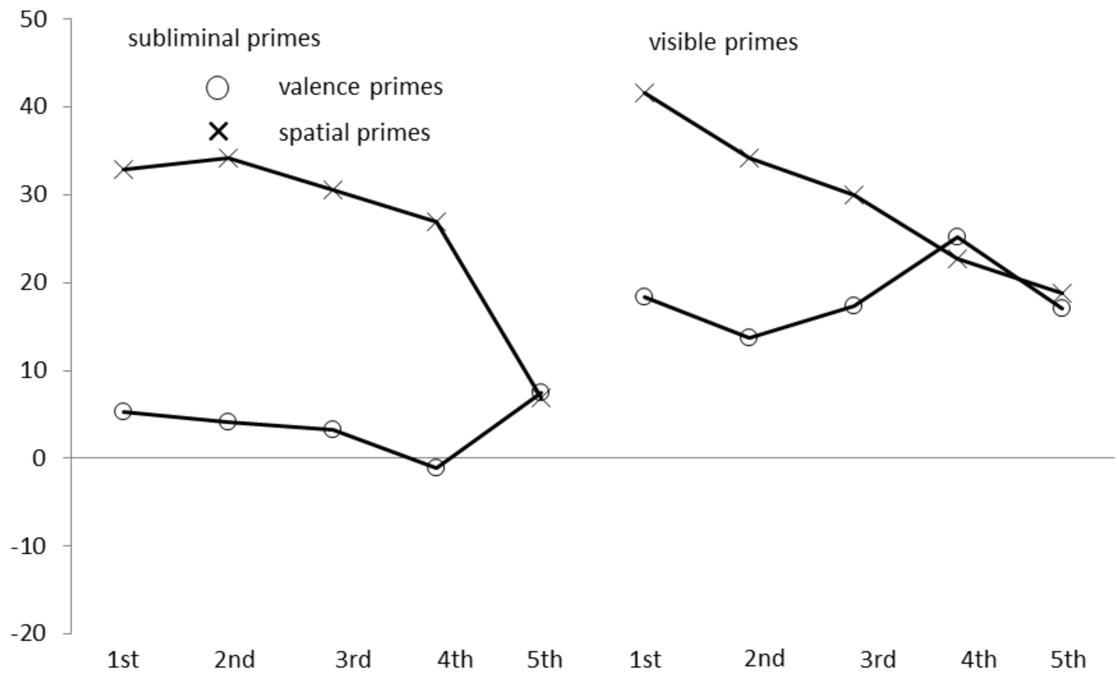

Figure 3: Mean congruence effects in Milliseconds, calculated as mean correct Reaction Times (RTs in ms) of incongruent conditions minus mean correct RTs of congruent conditions in Experiment 2, as a function of prime type (circles: valence primes; crosses: spatial primes), prime visibility (left side: subliminal primes; right side: visible primes) and quintile (1st to 5th) of the RT distribution on the x axis.

In an ANOVA of the mean error rates (ERs), with the variables congruence, prime type, and visibility the main effects of congruence, $F(1, 38) = 6.18$, $p < .05$, partial $\eta^2 = 0.14$ (congruent ER = 3.6 %; incongruent ER = 4.3 %), and prime type, $F(1, 38) = 9.58$, $p < .01$, partial $\eta^2 = 0.20$ (spatial prime: ER = 4.5%; valence prime: ER = 3.4%), were also significant. These effects made clear that the congruence effect was not due to a speed-accuracy trade-off, whereas the faster RTs to spatial primes (compared to valence primes) came at the expense of higher ERs (for spatial primes than for valence primes). In addition, the two-way interaction of prime type and congruence was significant, $F(1, 38) = 9.55$, $p < .01$, partial $\eta^2 = 0.20$, and there was a significant three-way interaction, $F(1, 38) = 4.45$, $p < .05$, partial $\eta^2 = 0.11$. Follow-up *t*-tests to compare congruent with incongruent ERs, conducted separately for the different combinations of prime types and prime visibility, revealed that the three-way interaction reflected the same tendencies that we observed in the RTs, standard congruence effects (with advantages in congruent relative to incongruent conditions) in all priming conditions (unmasked/spatial primes: 1.1%; masked/spatial primes: 2.3%; unmasked valence primes: 0.3%) but a reverse congruence effect for masked valence primes (-1.7%).

Supplementary information concerning polarity-correspondence effects. This time, we did not even find the expected facilitation of +pole targets as compared to –pole targets and no difference in the respective congruence effects of these targets alike. For the results see Table 2.

Prime visibility tests. The masked primes were invisible as demonstrated by the participants' mean chance performance. Mean *d'* was not significantly different from zero. It was 0.02, $t < 1.00$, with the masked spatial primes, and it was 0.10, $t(38) = 1.19$, $p = .24$, with the masked valence primes. In addition, the correlation between individual *d'* values and individual Cohen's *D* indices of congruence effects demonstrated that there residual visibility of masked primes did not significantly affect RT congruence effects of masked spatial primes, $r(39) = –.07$, $p = .67$, and of masked valence primes, $r(39) = .07$, $p = .67$. The same participants were able to discriminate between the unmasked prime-target relations. Mean *d'* was 2.70, $t(38) = 18.82$, $p < .01$, with the unmasked spatial primes, and it was 3.43, $t(38) = 30.87$, $p < .01$, with the unmasked valence primes.

Discussion

In Experiment 2, we found no significant across-category congruence effect based on masked valence primes. This is in contrast to the predictions based on quick (conditionally) automatic affective processes influencing semantic analysis and it is also in contrast to Experiment 1 in which we found an across-category congruence effect of the masked spatial primes. Together, the results point to an asymmetry between the sensory and the affective processing of the word meanings. Also, in line with prior research, an across-category effect of the visible valence primes showed that if strategic processing (or other forms of awareness-dependent processing) was allowed, we replicated the standard across-category congruence effect with the valence primes, too. Evidently, only the awareness-independent aspect of the valence-based across-category priming was prevented. This result fits well with recent findings from vision sciences, where it was found that image content is partly available before its evaluation (Nummenmaa et al., 2010).

In addition, our RT distribution analysis was suggestive of a category-based congruence effect of the valence primes and of a response-activation effect of the spatial primes. The congruence effect of the spatial primes decreased with an increasing RT which is typical of a response-activation effect (Ansorge et al., 2010; Kinoshita & Hunt, 2008). By contrast, the congruence effect of the visible valence primes was approximately the same for the different quintiles of the RT distribution which is the finger print of a category-congruence effect (Kinoshita & Hunt, 2008).

Despite this qualitative similarity of the result patterns in Experiments 1 and 2, there were also a few important differences. First, the congruence effect of the visible spatial primes in the present experiment did not decrease to zero with an increasing RT, whereas the congruence effect of the visible valence primes in Experiment 1 was completely eliminated among the slowest responses. Second and related, in the current experiment, the residual congruence effect of the visible spatial primes in the slowest responses was of about the same size as that of the visible valence primes. These differences might reflect more average semantic congruence between different spatial words than between different emotional words, and could reflect unique sources of meaning differences between the congruent emotional words. Even valence-congruent emotions, such as sadness and anger (both negative) or pride and loving (both positive) vary drastically according to further word-meaning dimensions, like arousal (Russell, 1980; Wundt, 1896) (which would be low for sadness but high for anger). These differences might have counteracted the valence-based congruence effect but no such diminishing influence seems to have been present with the spatial words.

Experiment 3

It is also possible that the across-category priming effect of the spatial primes in Experiment

1 reflected a type of intention-independent or truly stimulus-driven priming effect instead of a conditionally automatic across-category congruence effect. Experiment 3 was therefore an additional control experiment. The control experiment was conducted to experimentally rule out an interpretation of Experiment 1's across-category congruence effect in terms of a strongly automatic, bottom-up priming effect. As explained above, we assumed that Experiment 1's across-category congruence effect probably reflected that the prime's sensory meaning affected the task-relevant categorical evaluation of the valence targets as negative versus positive. If this was the case, it should be possible to abolish the across-category congruence effect. Past research has shown that participants can flexibly change their prime analysis in accordance with the instructions and the changing target-categorization requirements (Eckstein & Perrig, 2007; Klinger et al., 2000; Norris & Kinoshita, 2008). For example, Klinger et al. (2000) asked their participants to classify the same visible targets as either positive versus negative targets in one condition but as animate versus inanimate targets in a second condition. These authors found that only the prime-word meaning that was currently relevant for classifying the targets created an awareness-independent congruence effect. For example, if the participants classified the target words on the basis of the target's valence, a target-congruently evaluated prime facilitated responses as compared to a target-incongruently evaluated prime. By contrast to this, it did not matter whether both prime and target were of the same animate or inanimate category or whether one denoted an animate object and the other an inanimate object. This pattern of results was reversed when the participants had to classify the targets on the basis of the targets' category-membership to the categories of animate versus inanimate objects. Now the valence-based congruence effect was eliminated but a congruence effect on the basis of the status of the primes as names for animate versus inanimate objects was found.

From this it follows that we should be able to abolish a conditionally automatic across-category congruence effect when we no longer require categorization of the positive versus negative targets as two different categories. Here, we achieved this by changing the instructions and asking the participants to categorize both kinds of valence targets, negative and positive words, as belonging into the same class of objects. To that end, we used both valence and space words as primes *and* targets and asked our participants to categorize the targets into emotional adjectives on the one hand and into spatial prepositions on the other. Under these conditions, both negative and positive words belong to the same category. Hence, a conditionally automatic priming effect of the different spatial primes (i.e., up- vs. down words) on the categorization into negative and positive target words should be abolished because the difference between the emotional valences would no longer be relevant for the task at hand (Klinger et al., 2000; Eckstein & Perrig, 2007).

Method

Participants. For the new experiment, one participant with epilepsy was not tested, and another eight participants failed on the prime-discrimination criterion[1] as in Experiments 1 and 2. The remaining thirty participants (25 female, M_{age} = 24.1 years, age range: 21–38 years) were analyzed.

Apparatus, stimuli, and procedure were the same as in Experiment 1, except for the following differences. First, in the target-response task, participants had to discriminate between valence targets and spatial targets. Thus, in contrast to Experiment 1, all words were used as targets and as primes. However, to prevent combinatorial explosion, we used only the across-category prime-target combinations of major interest. (During prime discrimination, participants had to judge whether prime-target pairs were space-valence congruent or whether they were space-valence incongruent.)

Results

Target-response task. For the results, see also Figure 4. Of all responses, 4.2% were excluded by the same criterion as was used in Experiments 1 and 2.

In contrast to the preceding experiments, in an ANOVA with the variables congruence (space-valence congruent vs. incongruent), prime type/target type (valence primes/spatial targets; spatial primes/valence targets), prime visibility (masked prime vs. visible prime), and quintiles of the RT distribution (1st to 5th quintile) there was no significant main effect of congruence, $F(1, 29) = 1.08$, $p = .31$, partial $\eta^2 = 0.04$, and there was neither a significant interaction of congruence and prime type, $F < 1.00$, or of congruence and prime visibility, $F < 1.00$. The same was true of the other interactions with the variable congruence, all *p*s > .15.

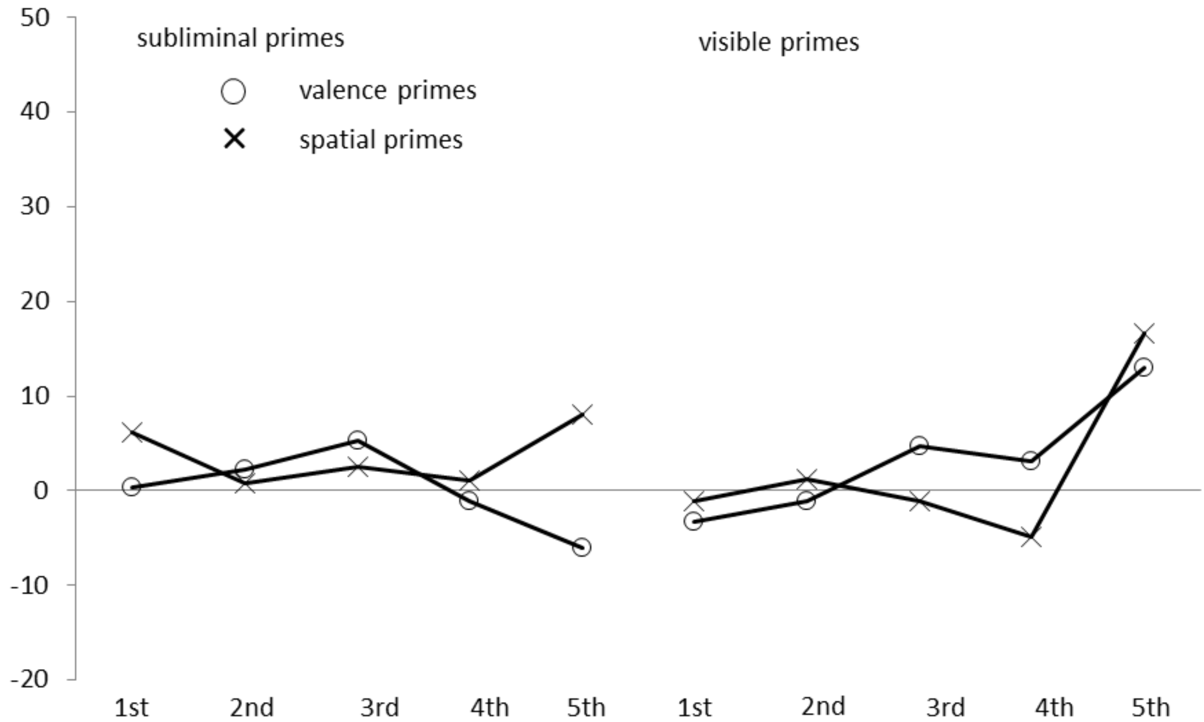

Figure 4: Mean congruence effects in Milliseconds, calculated as mean correct Reaction Times (RTs in ms) of incongruent conditions minus mean correct RTs of congruent conditions in Experiment 3, as a function of prime type (circles: valence primes; crosses: spatial primes), prime visibility (left side: subliminal primes; right side: visible primes) and quintile (1st to 5th) of the RT distribution on the x axis.

What we found were significant main effects of prime type, $F(1, 29) = 12.65$, $p < .01$, partial $\eta^2 = 0.30$, of prime visibility, $F(1, 29) = 4.75$, $p < .05$, partial $\eta^2 = 0.14$, and of quintile, $F(4, 116) = 298.31$, $p < .01$, partial $\eta^2 = 0.91$, $\varepsilon = .27$. Responses were faster for spatial primes/valence targets (RT = 695 ms) than for valence primes/spatial targets (RT = 715 ms) and for visible primes (RT = 697 ms) than for masked priming conditions (RT = 714 ms). Also, RT increased over the RT distribution. In addition, there was a significant Prime Type/Target Type × Quintile interaction, $F(4, 116) = 4.84$, $p < .05$, partial $\eta^2 = 0.14$, $\varepsilon = .47$, that was due to a steeper increase of the curves for space primes/valence targets than for valence primes/spatial targets (see Figure 4). To put it differently, the faster RTs for spatial primes/valence targets that we observed in a main effect of prime type/target type were stemming from the fastest responses, whereas there were no large differences between the RTs in the different prime-type conditions among the slower responses.

In the ANOVA of the ERs, we observed a significant interaction of congruence and prime type, $F(1, 29) = 4.68$, $p < .05$, partial $\eta^2 = 0.14$. Post-hoc *t* tests showed that this was due to a non-significant ‘standard’ congruence effect (0.7%), $t(29) = 1.66$, $p = .1$, for the spatial priming/valence target conditions and an almost significant ‘reverse’ congruence effect (-1.1%) in the valence prime/spatial target conditions, $t(29) = 1.89$, $p = .07$. In addition, a significant interaction of prime type and visibility, $F(1, 29) = 7.64$, $p < .01$, partial $\eta^2 = 0.21$, reflected that at least with the valence primes the faster RTs in unmasked than masked conditions (see RT ANOVA above) came at the expense of a higher ER in unmasked (7.2%) than masked (5.1%) conditions, $t(29) = 2.50$, $p < .05$, whereas with spatial primes no such difference was found (spatial primes: unmasked ER = 5.1%; masked ER = 5.4%, $t[29] = 1.66$, $p = .11$). The main effects, all non-significant *F*s < 2.60, all *p*s > .19, all partial η^2s < 0.09, and the remaining interactions, all non-significant *F*s < 1.10, all *p*s > .32, all partial η^2s < 0.04, were not significant.

Prime visibility tests. Again, the participants were unable to discriminate the masked prime-target pairs. For the masked spatial primes, *d’* amounted to 0.07, $t < 1.00$. For the masked valence primes, *d’* was 0.13, $t(29) = 1.51$, $p = .14$. Participants were capable of discriminating the prime-target relations with the unmasked primes. For the unmasked spatial primes, *d’* was 1.53, $t(29) = 6.65$, $p < .01$. For the unmasked valence primes, *d’* amounted to 2.08, $t(29) = 7.80$, $p < .01$.

Discussion

In Experiment 3, we wanted to rule out that the masked priming effect reflected a strongly automatic stimulus-driven effect. This was tested in this control experiment, in which all valence targets required one response and all spatial targets the alternative response. Under these conditions, if the masked priming effect was conditionally automatic, the spatial meaning of the primes should not have facilitated a categorization of the valence targets into negative versus positive words because valence discrimination was no longer required. As a consequence, the typical conditionally automatic categorization-congruence effect was expected to disappear because the categorization-congruence effect critically depends on an appropriate top-down categorization criterion on the side of the participants (Eckstein & Perrig, 2007; Klinger et al., 2000; Norris & Kinoshita, 2008).

An alternative prediction, however, was made for the control experiment if the congruence effect was due to stimulus-driven priming. If the spatial primes activated particular valence meaning in the preceding experiments in a stimulus-driven way, the congruence effect of the primes should have been found in the control conditions of Experiment 3, too, because the same primes and targets as in the preceding experiments were used.

At variance with this prediction, however, our results indicated that no congruence effect could be found in the present experiment. Thus, the data were much better in line with an origin of the across-category congruence effect in Experiments 1 and 2 via facilitation of the task-dependent target-category classification into positive versus negative words than via the stimulus-driven priming of one particular meaning.

Note also that the current experiment ruled out that the across-category priming effect in the supraliminal control conditions of Experiments 1 and 2 was an artifact of our procedure to ask the participants for a prime-target congruence judgment in the prime-visibility test. One might want to argue that asking the participants to categorize primes and targets as congruent or incongruent in the across-category priming conditions created the supraliminal across-category priming effect (in the second blocks – that is after the first prime visibility test at the end of the first block) of the preceding Experiments 1 and 2 in the first place. If this would have been the case, the same across-category congruence effect should have been found in the supraliminal conditions of the present experiment because the same prime-target visibility judgment as in Experiments 1 and 2 was also required in the present Experiment 3. However, in contrast to this prediction, no across-category congruence effect could be found in the supraliminal conditions of the present experiment either. These results are better in line with an explanation of the across-category congruence effect in terms of the facilitating and/or interfering influence of spatial meaning during the participants' discrimination between different positive and negative word valences.

General Discussion

Since about twenty years, an increasing number of experiments firmly established the existence of a space-valence congruence effect (Lakoff & Johnston, 1989). The space-valence congruence effect reflects an advantage for the classification of and responses to combinations of associated (or congruent) spatial and affective meaning, such as the classification of positive words at elevated locations, as compared to less associated (or incongruent) meaning, such as negative words at elevated locations (Meier & Robinson, 2004). Such across-category congruence effects are potentially very informative with respect to the connection between cognition and emotion (Eder, Hommel, & De Houwer, 2007).

One particular question that haunts researchers in this domain is the sequence of events during semantic analysis of words in general and the meaning-connected evaluations in particular. On the one hand, evaluations of words and objects are very swift and automatic (Arnold, 1960) and they can occur before or outside of awareness (Naccache et al., 2005). On the other hand, some semantic information also seems to lay aground of subsequent evaluations and therefore some forms of non-evaluative meaning extraction might have to precede evaluations (Storbeck & Clore, 2007). In line with this view, non-evaluative semantic classifications are sometimes faster than evaluative classifications (Nummenmaa et al., 2010) and non-evaluative and evaluative semantic classifications can both occur independently of awareness, too (Kiefer, 2002).

To investigate these issues during lexical access to word meaning in general and the case of the space-valence association in particular, we used subliminal priming with words as primes and targets. Subliminal priming of words allows measuring of an awareness-independent quick and (conditionally) automatic congruence effect based on the degree of congruence or fit between subliminal priming word and to-be-classified target word. Here, this method was used to investigate one particular source of non-evaluative semantic impact on valence assignments that has been emphasized as important by the defenders of an embodied-cognition view on emotions: the impact of sense-related (or sensory) non-evaluative meaning on emotions (Niedenthal, 2007). If the quick extraction of sensory non-evaluative meaning impacts on emotions, we expected an across-category priming effect of subliminal (masked) spatial prime word meaning on the classification of the valence of the visible target words. A corresponding awareness-independent across-category congruence effect was found in the present Experiment 1.

In addition, if evaluations also occur so quickly as to influence non-evaluative semantics used in sense-related classifications of words, we expected a similar congruence priming effect of subliminal valence words on the classification of the spatial elevation-meaning of visible target words. In contrast to this prediction, however, this across-category congruence effect was not found with subliminal valence word primes (Experiment 2). The across-category congruence effect of the valence prime words on the categorization of the spatial target words was only found with clearly visible supraliminal valence primes. The latter effect presumably reflected a strategic processing elicited by the prime words themselves and was therefore dependent on the use of clearly visible valence prime words (Forster, 1998). Such strategic processing of the visible prime words concerns the alteration of the prime processing that owes to their conscious recognition. For example, visible primes might have offered more opportunities for the participants' attentional dwelling on their meaning than masked primes and the amount of attention indeed seems to be an important mediator for space-valence congruence effects (Santiago et al., 2012). Related, once the participants can see the primes, participants might want to learn whether the prime categories predict the target categories. If the participants adopt such a strategy, they will be willingly processing both the meaning of the prime words and that of the target words. As a consequence, the prime meaning can then influence processing of the target meaning even in valence-space across-category prime-target word pairings where this kind of influence would otherwise not be possible. Together, the significant across-category congruence effect of the supraliminal primes and the absent congruence effect of the subliminal primes in the conditions with valence primes and spatial targets also made clear that a qualitative difference existed between aware and unaware processing modes.

In addition, in Experiments 1 and 2, we also found motor-activation effects of the primes in the within-category priming conditions. Here, the prime words were from the same set as the target words so that the prime words had the power to elicit a target-associated response alternative (Klinger et al., 2000; Kunde et al., 2003). In these conditions, a quickly dissipating congruence effect was found, also for the subliminal valence words (see Experiment 1). The fact that this congruence effect decreased over RT was in line with its assumed origin on a response-activation level (Kinoshita & Hunt, 2008). Note that this kind of response-activation effect probably reflected the task-dependent motor meaning of the words. Therefore, these motor priming effects could not account for the across-category congruence effects in Experiments 1 and 2 in which the priming words were from a different category than the response-relevant target and were never used as response-relevant stimuli (Klauer et al., 2007; Naccache & Dehaene, 2001). In addition, no stimulus-driven automatic across-category priming effect could be found once the valence discrimination was no longer required (Experiment 3).

Moreover, two further observations suggested that the awareness-independent across-category congruence effect reflected an influence of the primes on the targets' semantic categorization. First, the fact that the across-congruence effect in Experiment 3 was absent is in line with its origin on the level of a category-priming effect because subliminal semantic category-priming effects are conditional on a fitting task set (Eckstein & Perrig, 2007; Kunde et al., 2003; Norris & Kinoshita, 2008). Second, in Experiments 1 and 2 the across-category congruence effect in the subliminal and supraliminal priming conditions were more or less of a similar strength across the RT distribution (Kinoshita & Hunt, 2008). Jointly, our data were thus in line with a swift and awareness-independent influence of semantic processes on evaluations in general (Numenmaa et al., 2010; Storbeck & Clore, 2007), and of sense-related non-evaluative meaning on emotions in particular (Niedenthal, 2007).

This is not to say, however, that awareness-independent processing of non-evaluative meaning always has to precede evaluative processing. To note, we have studied the sequence of non-evaluative versus evaluative meaning extraction with regard to only one particular class of stimuli (words) and one particular type of non-evaluative meaning (spatial meaning). We can therefore not tell whether a similar sequence holds with other stimuli and alternative types of meaning. It is possible for example that specific valence stimuli, such as emotional facial expressions, are processed as quickly or even quicker than certain stimuli with a non-evaluative meaning. In line with this assumption, for example, participants are able to process subliminal facial expressions (Jolij & Lamme, 2005; Smith, 2011) even without a specific categorization task (Naccache et al., 2005). In fact, sensory or sensorimotor representations of affective facial expressions could be one valence-specific way of the embodiment of evaluative meaning (Niedenthal, 2007) – that is, the distinction of evaluative and non-evaluative meaning might not be feasible with regard to stimuli, such as human faces.

One further aspect that requires a brief discussion is our visibility measure. One might argue that with the current procedure of asking the participants to classify prime-target pairs after the preceding target responses, we could have underestimated the masked primes' visibility and prime judgments might have been influenced by the fluency of the target responses (e.g., prime judgments might have occurred earlier in congruent than incongruent conditions, allowing for more forgetting of priming information in incongruent conditions). However, when exactly the same timing, sequence, size, luminance, and positioning of the primes and masks were used with different prime-visibility tasks in a preceding study, the same results were found: Prime visibility is also zero if the prime judgments are given in separate blocks of trials without preceding target responses, and if the prime judgment concerns the classification of the primes alone instead of the prime-target categorization (Ansorge et al., 2010). Thus, we are confident that the present finding of prime invisibility in the masked priming conditions is not just an artefact of the particular method that we have chosen.

As a final cautionary remark, however, an asymmetry of the masked priming effect (of space concepts on valence but not of valence on space) as we have found it might also be in line with some characteristics of language use, such as frequent metaphorical reference to abstract concepts (here: valence) by more concrete concepts (here: spatial meaning) (Lakoff & Johnson, 1980; Santiago et al., 2012), whereas the asymmetry of masked priming effects might be at variance with some particular explanations of the space-valence congruence effect (Meier & Robinson, 2004; Walsh, 2003).

Conclusion

The present study shows that subliminal spatial words affected classification of associated valence word meaning but that there was no corresponding influence of subliminal valence words on the classification of spatial word meaning. This was different with supraliminal words where the influences of space on valence and of valence on space were reciprocal. Jointly, these data suggest that spatial word meaning can precede access to valence word meaning to create space-valence associations in word understanding, and that space-valence meaning associations with aware and unaware words are owing to partly different processing strategies.

References

Ansorge, U., & Bohner, G. (in press). Investigating the association between valence and elevation with an implicit association task that requires upward and downward responding. *Universitas Psychologica*.

Ansorge, U., Fuchs, I., Khalid, S., & Kunde, W. (2011). No conflict control in the absence of awareness. *Psychological Research*, *75*, 351-365.

Ansorge, U., Kiefer, M., Khalid, S., Grassl, S., & König, P. (2010). Testing the theory of embodied cognition with subliminal words. *Cognition*, *116*, 303-320.

Ansorge, U., Reynvoet, B., Hendler, J., Oettl, L., & Evert, S. (in press). Conditional automaticity in subliminal morphosyntactic priming. *Psychological Research*.

Arnold, M. B. (1960). *Emotion and Personality.* New York: Columbia University Press.

Baars, B. (1988). *A cognitive theory of consciousness*. New York: Cambridge University Press.

Bargh, J. A. (1992). The ecology of automaticity: Toward establishing the conditions needed to produce automatic processing effects. *American Journal of Psychology, 105*, 181-199.

Barsalou, L., W. (1999). Perceptual symbol systems. *Behavioural and Brain Sciences, 22,* 577-660.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59,* 617–645.

Cheesman, J., & Merikle, P. M. (1985). Word recognition and consciousness. In D. Besner, T. G. Waller, & G. E. MacKinnon (Eds.), *Reading research: Advances in theory and practice* (pp. 311-352). New York: Academic Press.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, *82*, 407-428.

Crawford, L. E., Margolies, S. M., Drake, J. T., & Murphy, M. E. (2006). Affect biases memory for location: Evidence for the spatial representation of affect. *Cognition and Emotion*, *20*, 1153-1169.

Damian, M. F. (2001). Congruity effects by subliminally presented primes: Automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance*, *27,* 154-165.

Dehaene, S., & Naccache, L. (2001). Towards a cognitive neuroscience of consciousness: Basic evidence and a workspace framework. *Cognition*, *79*, 1-37.

De Houwer, J., Hermans, D., Rothermund, K., & Wentura, D. (2002). Affective priming of semantic categorization responses. *Cognition and Emotion, 16*, 643-666.

Eckstein, D., & Perrig, W. J. (2007). The influence of intention on masked priming: A study with semantic classification of words. *Cognition*, *104*, 345-376.

Eder, A. B., Hommel, B., & De Houwer, J. (2007). How distinctive is affective processing? On the implications of using cognitive paradigms to study and affect and emotion. *Cognition and Emotion, 21*, 1137-1154.

Eder, A. B., & Rothermund, K. (2008). When do motor behaviors (mis)match affective stimuli? An evaluative coding view of approach and avoidance reactions. *Journal of Experimental Psychology: General*, 137, 262-281.

Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 680-698.

Galliard, R., Del Cul, A., Naccache, R., Vinckier, F., Cohen, L., & Dehaene, S. (2006). Nonconscious semantic processing of emotional words modulates conscious access. *Proceedings of the National Academy of Sciences USA*, *103*, 7524-7529.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, *9*, 558-565.

Gozli, D. G., Chasteen, A. L., & Pratt, J. (in press). The cost and benefit of implicit spatial cues for visual attention. *Journal of Experimental Psychology: General*.

Greenwald, A. G., Abrams R. L., Naccache, L., & Dehaene, S. (2003). Long-term semantic memory vs. contextual memory in unconscious number processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 235-247.

Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science*, *273*, 1699-1702.

Horstmann, G. (2010). Tone-affect compatibility with affective stimuli and affective responses. *Quarterly Journal of Experimental Psychology*, *63,* 2239-2250.

Horstmann, G., & Ansorge, U. (2011). Compatibility between tones, head movements, and facial expressions. *Emotion*, *11*, 975-980.

Jescheniak, J. D., & Levelt, J. M. (1994). Word frequency effects in speech production: Retrieval of syntactic information and of phonological form. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 824-843.

Jolij, J., & Lamme, V. A. (2005). Repression of unconscious information by conscious processing: Evidence from affective blindsight induced by transcranial magnetic stimulation. *Proceedings of the National Academy of Sciences*, *102*, 10747-10751.

Kiefer, M. (2002). The N400 is modulated by unconsciously perceived masked words: Further evidence for a spreading activation account of N400 priming effects. *Cognitive Brain Research*, *13*, 27-39.

Kiefer, M., & Brendel, D. (2006). Attentional modulation of unconscious semantic processes: Evidence from event-related potentials in masked priming paradigm. *Journal of Cognitive Neuroscience*, *18*, 1-15.

Kissler, J., Herbert, C., Peyk, P., & Junghöfer, M. (2007). Buzzwords. Early cortical responses to emotional words during reading. *Psychological Science, 18,* 475-480.

Kinoshita, S., & Hunt, L. (2008). RT distribution analysis of category congruence effects with masked primes. *Memory & Cognition, 36*, 1324-1334.

Kinoshita, S., Mozer, M. C., & Forster, K. I. (2011). Dynamic adaptation to history of trial difficulty explains the effect of congruency proportion on masked priming. *Journal of Experimental Psychology: General, 140*, 622-636.

Kintsch, W, & van Dijk, T. A. (1978). Toward a model of text comprehension and production. *Psychological Review, 85*, 363-394.

Klauer, C.-K., Eder, A., Greenwald, A. G., & Abrams, R. L. (2007). Priming of semantic classifications by novel subliminal prime words. *Consciousness and Cognition, 16*, 63-83.

Klauer, C.-K., & Musch, J. (2002). Goal-dependent and goal-independent effects of irrelevant evaluations. *Personality and Social Psychology Bulletin, 28*, 802-814.

Klinger, M. R., Burton, P. C., & Pitts, G. S. (2000). Mechanisms of unconscious priming. I. Response competition, not spreading activation. *Journal of Experimental Psychology: Learning, Memory and Cognition, 26*, 441–455.

Kunde, W., Kiesel, A., & Hoffmann, J. (2003). Conscious control over the content of unconscious cognition. *Cognition, 88*, 223-242.

Lakens, D. (2012). Polarity correspondence in metaphor congruency effects: Structural overlap predicts categorization times for bipolar concepts presented in vertical space. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*, 726-736.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago, IL: Chicago University Press.

Lamme, V. A. F. (2003). Why visual awareness and attention are different. *Trends in Cognitive Sciences, 7*, 12-18.

Lamme, V. A. F., & Roelfsema, P. R. (2000). The distinct modes offered by feedforward and recurrent processing. *Trends in Neurosciences, 23*, 571-579.

Lazarus, R. S. (1968). Emotions and adaptation: conceptual and empirical relations. In W. J. Arnold (Ed.), *Nebraska Symposium on Motivation* (Vol. 16, pp. 175-26). Lincoln, NE: University of Nebraska Press.

LeDoux, J. (1998). *The emotional brain: The mysterious underpinnings of emotional life*. New York: Simon & Schuster.

Macmillan, N. A., & Creelman, C. D. (2005). *Detection theory: A user's guide*. Mahwah, NJ: Lawrence Erlbaum.

Marcel, A. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology, 15*, 197-237.

Martens, U., Ansorge, U., & Kiefer, M. (2011). Controlling the unconscious: Attentional task sets modulate subliminal semantic and visuo-motor processes differentially. *Psychological Science, 22*, 282-291.

Meier, B. P., & Robinson, M. D. (2004). Why the sunny side is up. Associations between affect and vertical position. *Psychological Science, 15*, 243-247.

Melara, R. D., & O'Brien, T. P. (1987). Interaction between synesthetically corresponding dimensions. *Journal of Experimental Psychology: General, 116*, 323-336.

Meyer, D. E., & Schvanefeldt, R. W. (1976). Meaning, memory structure, and mental processes. *Science, 192(4234)*, 27-33.

Mulckhuyse, M., & Theeuwes, J. (2010). Unconscious attentional orienting to exogenous cues: A review of the literature. *Acta Psychologica, 134*, 299-309.

Naccache, L., & Dehaene, S. (2001). Unconscious semantic priming extends to novel unseen stimuli. *Cognition, 80*, 215-229.

Naccache, L., Galliard, R., Adam, C., Hasboun, D., Clémenceau, S., Baulac, M., Dehaene, S., & Cohen, L. (2005). A direct intracranial record of emotions evoked by subliminal words. *Proceedings of the National Academy of Sciences USA, 102*, 7713-7717.

Neumann, O. (1990). Direct parameter specification and the concept of perception. *Psychological Research*, *52*, 207-215.

Niedenthal, P. M. (2007). Embodying emotion. *Science*, *316*, 1002-1005.

Niedenthal, P. M., Winkielman, P., Mondillon, L., & Vermeulen, N. (2009). Embodiment of emotion concepts. *Journal of Personality and Social Psychology, 96*, 1120-1136.

Norris, D., & Kinoshita, S. (2008). Perception as evidence accumulation and Bayesian inference: Insights from masked priming. *Journal of Experimental Psychology: General*, *137*, 434-455.

Nummenmaa, L., Hyönä, J., & Calvo, M. G. (2010). Semantic categorization precedes affective evaluation of scenes. *Journal of Experimental Psychology: General, 139*, 222-246.

Osgood, C. E., Suci, G. J., & Tannenbaum, P. H. (1957). *The Measurement of Meaning*. Urbana.

Pessiglione, M., Schmidt, L., Draganski, B., Kalisch, R., Lau, H., Dolan, R. J., & Frith, C. D. (2007). How the brain translates money into force: A neuroimaging study of subliminal motivation. *Science*, *316*, 904-906.

Pessoa, L., Kastner, S., & Ungerleider, G. (2002). Attentional control of the processing of neutral and emotional stimuli. *Cognitive Brain Research, 15*, 31-45.

Plaut, D. C., & Booth, J. R. (2000). Individual and developmental differences in semantic priming: Empirical and computational support for a single-mechanism account of lexical processing. *Psychological Review*, *107*, 786-823.

Posner, M. I., & Dehaene, S. (1994). Attentional networks. *Trends in Neurosciences*, *17*, 75-79.

Reingold, E. M., & Merikle, P. M. (1988). Using direct and indirect measures to study perception without awareness. *Perception & Psychophysics*, *44*, 563-575.

Rey, G. (2003). Language of thought. In L. Nadel (Ed.), *Encyclopedia of cognitive science, Vol. 2* (pp. 753-760). London, England: Nature Group Press.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, *39*, 1161-1178.

Santiago, J., Ouellet, M., Román, A., & Valenzuela, J. (2012). Attentiona factors in conceptual congruency. *Cognitive Science, 36*, 1051-1077.

Scherer, K. R., Storr, R., & Johnstone, T. (2001). *Appraisal Processes in Emotion: Theory, Methods, Research.* Oxford: Oxford University Press.

Smith, M. L. (2011). Rapid processing of emotional expressions without conscious awareness. *Cerebral Cortex*, *22*, 1748-1760.

Spruyt, A., De Houwer, J., Everaert, T., & Hermans, D. (2012). Unconscious semantic activation depends on feature-specific attention allocation. *Cognition*, *122*, 91-95.

Spruyt, A., De Houwer, J., & Hermans, D. (2009). Modulation of automatic semantic priming by feature-specific attention allocation. *Journal of Memory and Language*, *61*, 37-54.

Stolarova, M., Keil, A., Moratti, S. (2006). Modulation of the C1 visual event-related component by conditioned stimuli: Evidence for sensory plasticity in early affective perception. *Cerebral Cortex*, *16*, 876-887.

Storbeck, J., & Clore, G. L. (2007). On the interdependence of cognition and emotion. *Cognition & Emotion, 21*, 1212-1237.

Weger, U., Meier, B. P., Robinson, M. D., & Inhoff, A. W. (2007). Things are sounding up: Affective influences on auditory tone perception. *Psychonomic Bulletin & Review*, *14*, 517-521.

Walsh, V. (2003). A theory of magnitude: Common cortical metrics of time, space and quantity. *Trends in Cognitive Sciences*, *7*, 483–488.

Wundt, W. (1896). *Grundriss der Psychologie* [Outlines of Psychology]. Leipzig: Engelmann.

Zajonc, R. B. (1980). Feeling and thinking: Preferences need not inferences. *American*

Psychologist, 35, 151-175.
Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Language comprehenders mentally represent the shapes of objects. *Psychological Science*, *13*, 168-171.

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Supported by Deutsche Forschungsgemeinschaft Grant An 393/5-1 to Ulrich Ansorge, Werner Klotz and Ingrid Scharlau, and by European Research Council's ERC-2010-AdG #269716 – MULTISENSE to Peter König. Thanks to Daniela Egerer, Katharina Sehling, and Caroline Rott for help with the data collection.

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Footnotes

[1] To ensure that the primes were not seen, individual d' scores were computed as a participant's difference between her/his z-transformed hit rate and the z-transformed FA rate during prime discrimination. The d' score becomes zero for chance performance and it can infinitely increase with an increasing number of correct judgments. Participants with an individual d' score above the confidence interval, calculated according to equation (1) (Macmillan & Creelman, 2005) were excluded from the analysis because of their potential capability to see the masked prime:

$$\Phi(p) = (2\pi)^{-1/2}\exp[-0.5z(p)^2]. \quad (1)$$

[2] Word counts of *'hasserfüllt'* included the word hass (*'hatred'*) and word counts of *'abfallend'* included the word *'fallend'* (*'falling'*).

[3] We are grateful to Daniël Lakens for pointing these predictions out to us.

[4] We were concerned that the congruence effect of the subliminal spatial primes could have reflected transfer of priming effects from preceding unmasked to masked blocks. Therefore, a complementary ANOVA was run with the additional between-participants variable block sequence (masked primes first vs. unmasked primes first), and the within-participant variables congruence, prime type, and visibility, as before. In addition to the significant results of the primary ANOVA, we observed a significant three-way interaction of sequence, prime-type, and prime-target congruence, $F(1, 38) = 4.19$, $p < .05$, and partial $\eta^2 = 0.10$. This three-way interaction reflected that a significant congruence effect (incongruent RT minus congruent RT) was found for all prime types [all significant congruence effects > 11 ms; all significant ts(19) > 2.40, all significant ps < .05) but for the affective primes when unmasked primes were presented in the first block [congruence effect = 8 ms; $t(19) = 1.35$, $p = .19$]. Thus, the across-category priming effect of the masked spatial primes was not due to transfer from preceding visible priming blocks only.

8. Acknowledgements

First of all I would like to thank Prof. Dr. Peter König and Prof. Dr. Ulrich Ansorge for their untiring efforts during the supervision my PhD. I am also thankful to Prof. Dr. Kai-Uwe for his co-supervision and review of the thesis. It wouldn’t be possible without their constant efforts and guidance. I thank Prof. Dr. Matthew Finkbeiner at the ARC Centre of Excellence in Cognition and its Disorders, Macquarie University, Sydney, Australia, for his close collaboration in our subliminal face processing study. I am also grateful to all of my colleagues at the Department of Neurobiopsychology, Institute of Cognitive Science, University of Osnabrueck, Germany, and at the Department of Basic Psychological Research, Faculty of Psychology, University of Vienna, Austria. My colleagues proved to be very cooperative and provided me help whenever I needed. I would also like to thank many students at both departments who helped in the data collection of my thesis and acknowledge their efforts in the corresponding sections of the thesis. I am also thankful to my parents, my uncle Dr. Habib Ahmad and his family, Mr. Mohammad Nawaz Khan, Mr. Saif-ur-Rahman, and all teachers and friends for their care and support throughout my life. Last, but not least, I am very grateful to my wife Maida and little son Aasim for their patience and cooperation.