Child & Youth Affective Computing – Challenge Accepted.

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Abstract—**Affective Computing has shown effective and useful in a range of use cases, including HCI, emotionally intelligent tutoring, or depression monitoring. While these could be very useful to the younger among us – including in particular also earlier recognition of developmental disorders, usually research and even working demonstrators have been largely targeting an adult population. In times where fairness is a dominating topic in the world of AI, it seems timely to widen up to include children and youth more broadly as user group and beneficiary of the promises Affective Computing holds. To best support according algorithmic and technological development, here, we summarise the emotion development of this group over the years, which poses considerable challenges for automatic emotion recognition, generation, and processing engines. We also provide a view on the steps to be taken to best cope with these, including drifting target learning, broadening up on the 'vocabulary' of affective states modelled, transfer, few-shot, zero-shot, reinforced, and life-long learning in affective computing besides trustability.**

■ **"IT IS ALRIGHT TO CRY"** is a 2014 movie quote of Baymax – Disney's inflatable health companion which becomes best friend of a young individual. But would today's Affective Intelligence be able to pick up a child or young individual's low mood? In fact, the lion's share of works on Automatic Emotion Recognition, Generation, Processing, or related fields such as Sentiment Analysis bases on research on adult's affective display. This comes for a number of reasons, primarily including that their data – be it auditive, visual, textual, physiological, or in other form – is easier to obtain and share, e. g., due to lower protection standards.

This is best exemplified by the competitive research challenges held in the field: While the first ever research challenge on affect recognition – the Interspeech 2009 Emotion Challenge – was indeed based on children voices, follow-up challenges dealing with Affective Computing (e. g., AVEC, Interspeech ComParE, MEC, OMG, MuSe) featured adults only – in particular those dealing, e. g., with depression. This appears unfortunate beyond the pure perspective of AI fairness leaving out a large share of the population: in particular, aside from improving, e. g., child-computer interaction and smart e-learning by integration of artificial emotional intelligence, or inclusion of the

younger population share for depression monitoring, some use cases are uniquely opening up to this group, such as the earlier recognition of neurodevelopmental disorders, such as Autism Spectrum Condition, Fragile X, or Rett Syndrome by analysis of emotional cues or their lack [1]. From this perspective, it appears obvious that modelling of child and youth affect needs to be addressed more richly. To this end, we herein provide an overview on this challenge, the changes of affect over the years of development, and the arising demands for an AI modelling these. In detail, we first justify the relevance and define emotions of children and young individuals, then dive deep into their development, including the different stages over the years of development, before distilling the according requirements for Affective Computing targeting it.

RELEVANCE

In general, capturing emotions as early as possible has many implications for an individuals' well-being. Our momentary performance, health, academic achievements and social relationships greatly depend on our emotions. In particular, how (un-)pleasant a particular an event is experienced directly addresses someone's capability on how to deal with such an experience and may challenge someone's well-being in case of maladaptive coping strategies or emotion regulation deficits. However, emotions are influenced by numerous factors such as subjective experience, memories, and context and research proposed several theories to capture emotions [2]. Emotion constructs are heterogeneous, hence, the objective, reliable, and valid assessment of emotions provides a vast variety of measurements facing limitations such as, e. g., memory biases, and social desirability. Especially in children and adolescents, those limitations are even more striking, since emotions develop and are expressed differently in the young. In addition, the younger children are, the less the cognitive representation of an emotional state is reflected.

The field of affective computing may overcome those challenges and provides numerous assessment accesses that may capture in real time a more objective emotion representation. In addition, it allows to simulate and process affect, e. .g., for tutoring applications, interaction, or entertainment. We will therefore now introduce the emotional development in children and adolescents over time and discuss possibilities on how they may best be modelled by technological forthcomings using general machine and deep learning approaches.

DEFINITION

Although emotions are ubiquitous in people's everyday language and a major interest in psychology research, there are numerous theories and concepts about emotion definitions mirroring the complex interplay of different components (sensory, cognitive, physiological, expressive, motivational) over time. Several emotion theories have been developed in the past years, along most of which emotions are classified into three dimensions: valence, arousal, and dominance.

The definition of emotions by Gross and Thompson combines several key aspects of the emotion process that are included in other emotion theories (e. g., Scherer's Emotional Component Process Model (CPM), [2] [3]: "a person-situation transaction that compels attention, has particular meaning to an individual, and gives rise to a coordinated yet flexible multi-system response to ongoing person-situation transaction" [3] p. 5). Three elements are highlighted: i) emotions are produced, in case an individual is appraising an external or internal event (e. g., mental representation) as meaningful; ii) emotions obtain several levels: subjective experience, behaviour (including the expressive response) and the physiological reaction; iii) emotions are tendencies of reaction, that can be influenced by the individual (emotion regulation). Similarly, the CPM [2] reveals the emotional process that leads to an individual's perception and processing of negative and positive life experiences.

As an extension of this model, the Emotional Competence Model hypothesises that mental well-being and adverse psychopathology (e. g., anxiety, depression) greatly depends on a well-functioning emotional processes. This depends on the individuals' experienced emotional response, its perception of the situation, and an adequate appraisal and regulation of emotions. However, these factors differ greatly in the context of early years and depend on the cognitive as well as socio-emotional development of an individual.

YOUTH EMOTIONAL DEVELOPMENT

Despite the fact that emotions are ubiquitous and inter-individual distinctions are rather to be neglected, they vary greatly among different developmental phases until adulthood. In fact, the ability to perceive, interpret, and regulate emotions is increasingly viewed as one of the most important developmental tasks of childhood. Emotions have several functions in a human being, as, e. g., protection from external potential danger (fear), poisonous food (disgust) and ally in a social group (affection). To achieve those life supporting functions, specific strategies of information processing, differential abilities of attention control, or dealing with social situations, the further affective, cognitive, social, and personality development needs to be acquired.

Successful development of emotional competencies is associated with the adequate expression of several emotion components: i) appraisal of a situation, ii) understanding, and iii) perceiving the emergent physical, cognitive, and representational feelings of an emotion (in oneself and others) and iv) regulating this representation [2]. Adverse emotional competences are associated with negative behavioural outcomes, e. g., negative interpretations of ambiguous situations is a core element in depression. However, the acquisition of emotions takes several years and includes various stages of development, from preliminary emotions in infancy to complex emotions.

As all components of emotions, the developmental stages are not independent from another and although
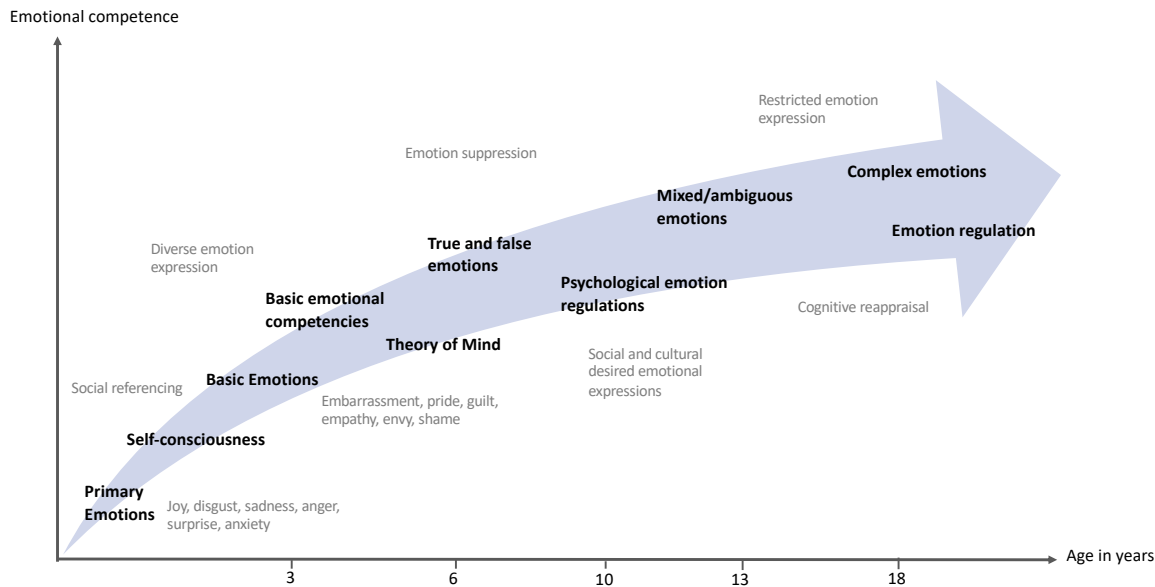
Figure 1. Youth emotional development

STAGES OF EMOTIONAL DEVELOPMENT

We now take a look at the development throughout 'discretised' time periods. For a visualisation of these, see Figure 1. For a detailed description, refer to Table 1.

Infancy. Who is not familiar with a heartbreaking baby's smile or an annoying baby's crying? From the very beginning, infants have the opportunity to express their feelings and needs (e. g., hunger), as they are not yet able to satisfy their needs themselves, but depend on their parents to fulfil them. Infants adapt quite quickly how to express their needs in order to attract their parents' attention and predict their parent's behaviour.

Although emotion regulation develops later, newborns already possess some basic strategies or precursor emotions [4], as they rely on signalling their distress or satisfaction to attract attention to ensure their care by the primary caregiver. Regarding perception of others' emotions, newborns are perceptible of their primary caretaker's emotional facial and vocal expression within the first weeks. They are able to differentiate negative and positive basic emotions (comfort/discomfort; arousal) [5]. Infants show a threefold emotional expressive behaviour by showing distress by crying and irritability, joy by smiling, and attention and interest in their surrounding [6].

At the age of three months, infants express joy and

begin to smile when they recognise known events (e. g., humans, animals) as well as sadness in case of an adverse event (e. g., withdrawal of the mother's attention). Other basic emotions as anger, frustration, surprise, and fear appear slightly later in the fourth to eighth months, since, e. g., fear requires more complex cognitive abilities. However, those basic emotions or 'action patterns' do not need to be learnt, but are innate in a human developmental program. An important developmental step in the acquisition of emotions is the cognitive ability of objective self-representation (recognising oneself, e. g., in the mirror, with six months). Due to this ability, the social emotions embarrassment, empathy, and envy evolve. When the cognitive development proceeds further and infants are capable of understanding expectations and rules by caregivers and culture, more complex social emotions as pride, shame, guilt and embarrassment are emerging – hence, all basic emotions are shown within the first nine months. To assess these emotions, the facial expression only is not sufficient anymore; voice and posture should be additionally taken into account at this age. Already at the age of three, children possess a variety of complex emotion in relation to cognitive appraisal processes that will further differentiate and transform in the following years. However, the basic emotions remain the same within this process.

Early Childhood. Between the second and fifth year, children take rapid steps in recognition and labelling of emotions [6]. From 18 months onward, the ability of self-awareness emerges as important precondition: more self-conscious (exposed) social emotions as embarrassment, pride, guilt, empathy, and envy develop further in the second year [6]. Moreover, between the age of two and three, children start to distinguish negative and positive emotions as 'sad' and 'happy' and use those words in

Table 1. Emotion development and emotional expression

Age	Emotion development	Emotional expression
Infancy		
First weeks	Distress Joy Interest	Crying, irritability, grimacing Smiling
3 months	Joy Sadness Disgust	'Social' smile, excitement, laughing Crying Spill out
2-6 months	Anger, frustration Social referencing: emotion regulation via others/caretaker	Fake crying
6 months	Surprise	Enjoyment of unexpected or odd events
7-8 months 9 months	Fear All basic emotions developed	Hiding behind caregivers
12-24 months	Self-conscious (exposed) emotions: Embarrassment, pride, guilt, empathy, envy	Hide behind hands, lower face, blush
30-36 months	Pride, shame Diverse emotional expression abilities	Voice and posture
Early Childhood		
3-6 years	Basic emotional competencies: understanding the causes of one's own and others' emotions Recognise and name emotional expressions in faces and photos	Adoption of pretended expressive behaviour, expression of 'blended' emotions
Childhood		
4-6 years	Theory of mind: change of perspective Understand true and false emotions: ability to recognise and produce social and cultural desired emotional expressions (4-6 years) Understand fake emotions (6 years +)	Adoption of 'cool emotional front' with peers (5-7 years)
6-10 years	Mixed and ambiguous emotions Behaviour based emotion regulations	Appreciation of norms for expressive behaviour, use of expressive behaviour to modulate relationship dynamics
8 years	Psychological emotion regulations (e. g., distraction) Social situations as triggers of emotion more common (more common in girls)	
Adolescence		
13-18 years	More intense experience of and higher fluctuations in emotions Meta-cognitions: Growing reflective abilities and flexible appraisal including cultural, social, personal, and situational factors in the emotion production Further development of disgust, anxiety and surprise, shame, jealousy, envy Cognitive reappraisal Growing empathy and change of interpersonal perspectives	Restricted emotion expression Skillful adoption of self-presentation strategies

simple contexts. With processing age and language abilities, the emotion vocabulary doubles between the pre-school age until the age of nine [7]. going along with more complex and differentiated emotion recognition and then emotion vocabulary. At the age of three,children begin to understand how external events may have an impact on emotions of other individuals, e. g., estimate someone else's sadness due to the death of a pet. From the age of three, the causes of one's own and others' emotions can be recognised and named. At the age of six, children are almost perfectly able to categorise emotion expressions to specific emotion related situations [7], while two-year-olds are especially good in recognising situations related to joy.

With processing age, children take the facial expression of an emotion into account to identify the emotional situation and are more and more skilled to integrate several emotion cues.

Childhood. The development and differentiation of basic emotional competencies takes place between the ages of three and six [8]. The acquisition of emotional competence can be described as one of the most important developmental tasks in toddler and preschool age. It promotes and forms a basis for other developmental areas [8]. In addition, the ability of change of the emotional perspectives (see below: the Theory of Mind), differentiation of true, false, and ambiguous emotions, as well as emotion

regulation are important steps within childhood.

Theory of Mind. One major concept and important developmental step in psychology is the ability of change of emotional perspectives – the so-called "Theory of Mind" – children acquire at the age between four and six years [9]. This includes the understanding of how human minds function having an impact on someone's behaviour. In addition to non-visible behaviour as thoughts, dreaming, forgetting, and sleeping, the Theory of Mind also includes wishes, beliefs, perception, and feelings. Here, the first step is the relation between wishes and emotions of others. Until the age of five, children are capable of anticipating someone else's emotional representation while, e. g., three year old children still face difficulties in this regard. For instance, a three-year-old child would state that red cap is afraid of visiting her grandmother's house since the wolf is waiting there, while five-year-old children already realise that red cap did not get this information and cannot be anxious as a consequence [9]. Harris et al. [9] discusses two processes in the acquisition of emotions within the Theory of Mind: i) a rapid, empathy-based process that is primarily based on wishes of the protagonist in a story and the ii) slower and more cognitive-based process that is depending on the protagonist's expectations of an event in a story. The second process requires further cognitive processing and apparently develops in a dynamic manner from the age of four.

True and false emotions. An adaptive emotion expression is a necessary skill to interact in an adequate way in social situations (e. g., show piety at a funeral, or be serious in a job interview) that underlie certain social and cultural display rules [10]. Hence, decoding and following such displaying rules is another important step in the development of emotions. At the age of three, children are not yet capable of differing pretended or false from true emotions. Children start to understand how pretended emotions are used to manipulate others and realise what effect fake emotions may have on others at the age of five. For six- to ten-year-olds, the differentiation of true and false emotions is not a problem anymore. Interestingly, girls and boys show different abilities in their masking behaviours: in two experimental settings, girls were observed to show more positively expressed emotions by receiving an unpleasant present (in comparison to a pleasant present), while boys did show less effort to mask their disappointment [6]. The older the children, the less negative was the emotional expression in case of disappointment in boys and girls, however, the gender effect remained significant. Apparently, children develop first the ability to control the emotional display and the differentiation between internal and external emotion representation (age four to six), but understand later (age six years plus) the meaning of the discrepancy [6]. The development of these abilities is furthermore related to the general understanding of emotions and to how an emotional expression may influence others. For example, showing joy over candy can encourage grandparents to provide more supplies. Understanding emotions in others was also shown to be helpful in recognising emotions of their social environment in seven-year-olds [10] and hence, is a helpful guidance in social situations for adequate behaviour preventing social rejection.

Ambiguous emotions. Understanding and integrating two (conflicting) emotions at the same time is a more difficult developmental task and therefore developing later starting at the age of six. In experimental tasks involving the presentation of a story with one negative and one positive event, six-year-olds focused on only one event (either the negative or the positive event) and neglected the other [11]. At the age of eight to ten, children still face difficulties in understanding that it is possible to experience two (ambiguous) emotions simultaneously. At the age of ten, children were shown the understanding of ambiguous emotions in relation to different contexts [11].

Emotion regulation. Regulating how emotions are expressed and experienced represents a basic skill for social interaction and mental well-being [3]. However, this skill is also rather complex and requires an advanced developmental state. In Gross and Thompson's model, two processes (internal and external) are responsible for monitoring, evaluating, and modifying emotional responses, including their temporal and intensity characteristics, to achieve one's goals [3] p. 27.). Between the stimuli and response attention, the appraisal of a specific situation tailors the resulting emotion [3]. E. g., talking in front of others can be frightening if someone fears to say something unsuited and the consequent social rejection. Those appraisals differ among the lifespan due to individual learning experiences, e. g., the experience of laughter in school due to a mistake. To actively intervene in the emotion production, a person has several options within the emotion production process (as shown in Figure 1): i) situation selection, ii) modification of the situation, iii) attention focus, iv) cognitive reappraisal, v) direct emotion modulation via relaxation techniques, substance (as drugs), or emotion display restrictions. Assessing emotion regulation is challenging in research, as it is difficult to distinguish from 'unregulated' emotions as a control condition. Those emotion regulating processes vary on a continuum from conscious and controlled to unconscious and automatic.

Small children mostly depend on the support of others to regulate their emotions (e. g., hugging while crying) and rely on 'social referencing' beginning at the age of six months [6]. Thereby, toddlers look for the emotional reaction of their caregiver in order to regulate their own emotions on this basis. At the age of one year, the parental emotional expression is the main important source, especially the facial expression, and further extended in the upcoming years to others like peers in school (and emotion expressions sources). Furthermore, as children grow older, emotion regulation shifts from the interpersonal to the intrapersonal realm and emotion control strategies become more advanced. This goes along with the expectations of others to handle impulses and to adapt to social norms and integrate into a social group (e. g., wait until it is their turn) [4].

ADOLESCENCE

Although the emotion acquisition process is more or less finalised within childhood, adolescence goes along with a deeper and more complex development of emotional competences. Simultaneously, adolescence depicts a special vulnerable phase due to hormonal and neurological changes in the development. The great plasticity of the adolescent brain allows environmental influences to have a particularly formative impact on cortical circuits, representing both an opportunity and a risk [12]. At the onset of puberty, activity of the prefrontal cortex increases, going along with behavioural inhibition via anger and rage increases [4]. In a longitudinal study assessing everyday emotions with ecological momentary assessment, 220 adolescents (aged 14-18 years) showed more negative emotions than four years earlier [13]. At the same time, the general mood was positive in 70 % of the responses. One interpretation is that the balance of affects is challenged within adolescents. Furthermore, the experience of emotions is more intense for both negative and positive emotions and changing in a rapidly manner compared to children and young adults [4] [13]. It was further shown that the range of emotion intensity was bigger, especially in girls, who experience more fluctuation in intense positive and negative emotions. More negative emotions and higher fluctuations were associated with negative experiences and depressive symptoms. However, those sex differences were larger in the early adolescence and diminished later on (up to 18 years). Although adolescents experience more intense emotions, this is not accompanied by a stronger expression of feelings [14]. This control of emotion expression is observed not only in negative emotions and potential 'vulnerabilities' (e. g., sadness, anxiety), but also in positive emotions and in various emotion-triggering situations (e. g., failure, provocation) [14]. The aim of emotion suppression – or 'playing cool' – is rejection avoidance by peers, and is what was shown to be especially important for boys [4]. In general, at this time, the peer group has great influence, e. g., on risk behaviour of adolescents. Managing the emotion expression flexibly depending on a particular situation and relationship due to the estimated consequences is an important achievement and requires emotional competences [15].

In adolescence, recognising and describing emotions in detail becomes increasingly easy and is accompanied by an expanded vocabulary. In addition, meta-cognitive skills develop and adolescents are able to reflect on emotion-eliciting situations, the appraisal, and the resulting emotion in a more flexible and advanced manner, including cultural, social, and personal factors. For example, they can attribute the specific event of an emotion that triggers anxiety, anger, or sadness [16]. In addition, adolescents are capable of differentiating mixed or ambiguous emotions and are able to articulate those. Adolescents were shown to distinguish the emotions sadness, anger, anxiety, and happiness in a more complex and detailed way than children [7]. Especially the emotions disgust, anxiety, and surprise develop further in the later years, while smaller children already recognise happiness, sadness, and anger quite well [17]. Naturally, the better representation, perception, cognitive flexibility (cognitive reappraisal), and expression of emotions improves emotion regulation abilities throughout adolescence. With growing years, adolescents are able to estimate the antecedents and outputs of emotional events and control their emotion expression. An important factor for the training of emotion modulation was shown to be close friendships: adolescents with close friends showed more anger-regulating skills [18]. Furthermore, emotional self-revelation abilities were associated with an increased number of friends over time. On the other hand, social withdrawal was correlated with social isolation and less friends [18].

INFLUENCING FACTORS

Although those emotion development steps are rather general, several individual and social influence factors shape the individual development of emotions quite substantially. Individual factors are the already mentioned cognitive development, including language, executive functions (e. g., problem solving skills, control of attention focus, or working memory), intelligence, gender, and temper. Social influence factors are parents, the parent-child relationship (or attachment), and familial relationships especially in the early years. During adolescence, peers, friends, the social economic status, and cultural norms are more important for the emotional development.

IMPLICATIONS FOR AFFECTIVE COMPUTING

In order to master the above sketched challenge of computationally modelling of young individuals' affect, we envision a number of steps to be required, as follow.

Learning with Drift As sketched above, the past is not the future when it comes to child and youth emotion display. Hence, machine learning algorithms have to be able to adopt to changes during the development of young users. This can be a hard problem from a machine learning perspective, but according solutions exist and need to be adopted to Affective Computing.

Ambiguous, Mixed, Regulated, and Social Emotions From the above it becomes clear that fully modelling children and youth affect includes beyond some 'classical' categories or dimensions ambiguous, mixed or regulated affect and richer facets of affect such as social emotions. Such have, however, in practice, hardly been modelled computationally so far.

Transfer, Zero-, and Few-Shot Learning The gradual changes across the years of development in affective behaviour and the required richness sketched above demand for excessive amounts of learning data. This hits hard in a field where data sparseness is an ever-present concern, due to the high labelling cost coming with mutiple labellers per data due to the subjective and uncertain nature of affect. This situation is even more severe dealing with the vulnerable group of children and youth. Hence, methods of transfer learning from adults or across ages and affects can

help to initially ease this requirement. If few data points can be collected from the target group, few shot learning can further improve such models. If such are not available, but the affective behaviour can at least be described as in this article and its references, zero-shot learning can be a last resort.

Reinforced Affective Computing A further alternative to cope with the low availability of suited data is provided by reinforcement learning. Rather than requiring labels, real-world interactions of an AI with children or youth with some kind of 'reward' feedback are needed for the AI to learn and adapt. For the recognition of engagement in children, this has been observed to boost performances considerably across modalities [19]. It needs, however, to be scaled up across developmental stages, and can help to cope with the data bottleneck if real-world affective applications can be turned into an agent-based reinforcement learning setting.

Life-long Learning If AI learns from children as they grow, it seems reasonable to make use of life-long learning strategies in order to avoid catastrophic forgetting of affective behaviour learnt across ages. Such approaches have already been demonstrated feasible in specialised ways [20], and need to be generalised across use-cases.

Trustworthy Affective Computing Finally, Affective Computing comes with considerable ethical challenges and demands. Given the named vulnerability of the target group concerned herein, however, trustworthiness of the affective AI is even more so a clear must. Among others, this will include safe and 'Dependable Affective Computing' following the principles of Dependable AI, yet to be established.

CONCLUSION

We highlighted the challenge of Affective Computing dealing with children and youth in modelling – be it for recognition, interpretation, processing, or simulation of respective affect. We provided an overview on the different affective abilities and portrayal changes during young individuals' development. This can serve as rough blueprint, guideline, and reference pointer in the development of according technical solutions. In addition, we distilled pressing requirements on the road to realise such. Most of these have not (e. g., learning with drift, or dependability) or yet sparsely (e. g., zero-, few-shot, reinforced, and life-long learning) been addressed in Affective Computing in general; hence, raising the challenge in realising these in this demanding context. Most of all, however, 'fair' AI will require children and youth to be equally provided with the promises Affective Computing holds – let us assure they will not only benefit, but can also rightfully trust in such technology.

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