What Gestures Do Users with Visual Impairments Prefer to Interact with Smart Devices? And How Much We Know About It

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Abstract
We examine gestures that people with visual impairments define and would like to use to control interactive devices and systems. To this end, we perform a systematic search of the literature on gesture elicitation consisting of 249 papers published between 1994 and 2019, from which we identify 12 studies (4.8%) that explicitly elicited gesture preferences from users with visual impairments and/or examined the consistency of their gesture articulations. We compile a set of 53 user-defined touch, motion, mid-air, and stroke-gestures to effect 44 functions on smartphones, TVs, and tangible UIs. We point to several lacunae in our community’s current knowledge of gestures preferred by users with visual impairments.

Introduction
As gesture user interfaces are implemented for more and more interactive systems and contexts of use, their accessibility for users with various abilities needs to be rigorously addressed. Touch, the prevalent input modality for smartphones [28], requires visuomotor coordination that is challenging for users with low vision [22], not to mention people who are blind. In this context, new input techniques [3,9,13], gesture recognizers [29], data synthesis approaches [12], and

Overview of gesture elicitation studies

The goal of a gesture elicitation study [39] is to collect, analyze, and document the gesture preferences of the representative end users of a specific gesture-based UI, application, system, or interactive prototype. A gesture elicitation study implements several steps [38,39]:

1. Participants are presented with the effect of a system function, *e.g.*, a map displayed by an interactive tabletop zooms out.
2. Participants are asked for the action that could generate the effect they have just witnessed. The effect is called the "referent" and actions are called "signs."
3. The researcher (designer, experimenter, etc.) analyzes the gestures to determine their level of agreement.
4. Gestures that receive high agreement are compiled into a "consensus gesture set" reflective of end users' behavior and preferences for gesture input in relation to the specific device, application, or system investigated in the study.

Variations of this procedure are possible, *e.g.*, in terms of how many gestures are elicited from the same participant [18,31] or the measure/method to compute the level of agreement for the elicited gestures [1,17,26,31].

multimodal UIs [5] are needed to make touchscreen devices accessible to users with visual impairments.

Gesture elicitation studies (GES) [38,39] are a practical tool for designers to understand users' gesture preferences to control interactive systems; see the side bar for an overview. Unfortunately, only a handful of such studies have been conducted for users with visual impairments despite the popularity of the method: from the 249 GES papers identified for this work, only 12 (4.8%) focused on users with visual impairments, of which just 4 (1.6%) actually reported a gesture set to guide designers in their work. In this context, more research is needed to understand and document the gestures preferred by users with visual impairments for a variety of interactive devices, applications, and contexts of use. In this paper, we conduct a systematic search and analysis of GES studies for users with visual impairments, and compile a vocabulary of 53 touch, motion, mid-air, and stroke gestures to effect 44 functions on smartphones, smart TVs, and tangible UIs.

Research Method

To identify GES studies with participants with visual impairments, we ran the query "(Gesture AND (Elicitation OR Guessability) AND Study)" on six digital libraries: ACM DL, IEEE Xplore, Science Direct, Springer Link, DBLP, and Google Scholar; see [35]. After removing duplicates and irrelevant papers, and running a snowballing procedure, we ended up with 249 papers that elicited gestures or applied parts of the GES method, *e.g.*, agreement measures, for gesture analysis. From these papers, we identified 12 studies (4.8%) involving participants with visual impairments. We analyzed these studies to extract information for meta-analysis (*e.g.*, the number of participants) and user-defined mappings between referents and gestures.

Results: Meta-Analysis

Table 1 lists the 12 papers identified by our systematic search. Of these, [15] and [16] report the same study, and [30] is an extension of [29] with more participants (54 *vs.* 20) and a different goal. We grouped these papers into four categories, as follows:

- Six papers [6,7,10,14,19,23] applied the GES method directly, and are marked with the "GES" acronym in Table 1, third column.
- One paper [36] used brainstorming [11] (marked "B" in Table 1) to implement gesture elicitation.
- Two papers [15,16] conducted a rating/ranking elicitation ("R/R") of predefined hand gestures.
- Three papers [4,29,30] performed gesture collection ("GC") without any referents but reported gesture agreement (consistency [2]) results.

The number of participants with visual impairments varied between 8 and 36 (M=19.1, SD=9.6), and most studies (8 of 12) addressed users who are blind. The number of referents varied from 6 to 31 (M=18.9, SD=8.6). Overall, the GES and B-type studies collected between 56 and 880 gestures (M=314.8, SD=290.0), but only four studies [6,7,23,36] actually reported consensus gesture sets. Most of the studies provided design guidelines for gesture UIs for users with visual impairments, while a few [6,23,29,36] implemented actual prototypes. Only three studies [10,29,30] involved users without visual impairments as a control group, while three papers [6,7,19] connected their findings to those reported by previous GES studies: [6] with [20], [19] with [10], and [7] with [25].

Table 1: Overview of the studies identified by our systematic search procedure that elicited gesture preferences or gesture articulations from participants with visual impairments.

	Study	Study type	Gesture types	Device / Context	User category	Participants #	M/F	Age [yrs.] Mean (SD)	Control group[1]	Num. referents	Num. elicited gestures	Consensus gesture set	Goal of the study / outcome
1	Kane *et al.*, 2011 [10]	GES	touch, stroke-gestures	10” tablet	Blind	10	4/6	49 (12.2)	Yes/10	22	880	n/a	Design guidelines
2	Dim and Ren, 2014 [6]	GES	motion gestures	smart phone	Blind	13	9/4	61 (16.91)	No,[20]	15	195	Yes	Implemented user interface
3	Romano *et al.*,2015 [19]	GES	touch, motion, stroke-gestures	iPhone 4S	Blind	8	4/4	61 (11.3)	No,[10]	19	278	n/a	Empirical study
4	Luthra and Ghosh, 2015 [14]	GES	touch and stroke-gestures	smart phone	Blind	12	10/2	31 (9.6)	No	25	300	n/a	Design guidelines
5	Dim *et al.*, 2016 [7]	GES	mid-air gestures	TV	Blind	12	7/5	53.9 (12.64)	No,[25]	15	180	Yes	Guidelines, methodology
6	Shi *et al.*, 2017 [23]	GES	tangible input	3D printing	Blind	12	4/8	40.8(13.2)	No	6	56	Yes	Guidelines, proposal
7	Modanwal and Sarawadekar, 2018 [15]	R/R	free-hand gestures	n/a	Blind	25	25	21.4 (2.3)	No	31[(2)]	1,550	n/a	Prototype
8	Modanwal and Sarawadekar, 2018 [16]	R/R	free-hand gestures	n/a	Blind	25	25	21.4 (2.3)	No	31[(2)]	1,550	n/a	Prototype
9	Wang *et al.*, 2019 [36]	B	touch gestures (with the ear)	smart phone	Blind, low vision	30	20/10	n/a	No	8	n/a	Yes	EarTouch prototype
10	Buzzi *et al.*, 2017 [4]	GC	touch and stroke-gestures	smart phone	Blind, low vision	36	22/14	F 25(14.3) M 50(16.8)	No	25[(3)]	812	n/a	Design guidelines
11	Vatavu, 2017 [29]	GC	stroke-gestures	10” tablet	Low vision	10	6/4	35.7(11.7)	Yes/10	12[(3)]	2,400	n/a	$P+ recognizer
12	Vatavu *et al.* 2018 [30]	GC	stroke-gestures	10” tablet	Low vision	27	12/15	29.1(12.3)	Yes/27	12[(3)]	6,562	n/a	Design guidelines

[1]Comparisons were conducted with participants without visual impairments (control group). [2]Not referents, but hand postures for which participants expressed their preferences. [3]Not referents, but gesture types that participants articulated during the study and their gestures were analyzed using measures of agreement (consistency) following Anthony *et al.* [2].

Results: User-Defined Gestures

From the GES and B-type studies that reported gesture sets [6,7,23,36], we extracted gestures with high consensus subsuming 44 referents and 53 gestures for smartphones, smart TVs, and tangible UIs. We compiled these results into a dictionary (see Table 2) with the goal to structure and synthesize prior work on gestures elicited from users with visual impairments (*i.e.*, what gestures were preferred in the specific context set by those studies?) and to accompany designer-proposed touch input, *e.g.*, “Slide rule” [9], “BrailleSketch” [13], or “Perkinput” [3], among others.

Table 2: Gestures with high consensus proposed by users with visual impairments [6,7,23,36]; also see Tables 3 and 4. *Note:* different colors indicate different gesture types: touch (green), motion (magenta), mid-air (black), and stroke gestures (blue).

Smartphone input

Answer call: bring phone to ear [6]; double-tap with ear [36]
Hang up call: remove phone from ear [6]; ear swipe [36]
Ignore call: cover the phone with the hand [6]; ear swipe [36]
Voice search: bring phone to mouth [6]; long ear press [36]
Call missed call: shake front-back and bring phone to ear [6]
Select: shake front-back [6]; ear double tap [36]
Home screen: turn phone back and front [6]

Table 3: Overview of the gesture types reported in the literature of end-user elicitation studies that were proposed by users with visual impairments; see Table 2 for details about these studies.

Gesture	Count	Refs.
Touch	18	[6,23,36]
Motion (device)	12	[6]
Mid-air	14	[7]
Stroke gestures	9	[6,23,36]
Total	**53**	

Table 4: Overview of the number of gestures per device type; see Table 2 for details.

Device	Count	Refs.
Smart phone	28	[6,36]
Smart TV	14	[7]
TUIs	11	[23]
Total	**53**	

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Next/Previous: flip phone right/left along vertical axis [6]
Pan: move phone to left, right, up, down [6]
Pause: cover the phone with the hand [6]
Power off: sweep hand on the phone from top to bottom [6]
Get caller info: tap with the ear [36]
Get time/battery level: ear tap at the top/bottom screen [36]
Mode switch: press with the ear [36]
Navigate: ear swipe [36]
Explore: free-form gesture with ear [36]
Show menu: rotate phone while pressed onto the ear to activate the menu and swipe to navigate menu items [36]
Continuous input: rotate phone while pressed onto the ear [36]

TV control

Turn TV on/off: perform tap in mid-air [7]
Play/pause TV: open/close palm [7]
Turn volume up/down: move palm upward/downward [7]
Change TV channel: hand rotates imaginary knob in mid-air [7]
Show TV guide: draw circle in mid-air [7]
Go to favorite TV channel: clap hands [7]
Show TV Menu: hands separate like opening a book [7]
Answer No: the index fingers of the two hands form a cross [7]
Answer Yes: the "OK" emblematic hand pose [7]
Go to previous/next channel: swipe hand left/right [7]
Voice guide: move both hands to ears [7]

Tangible interactions

Get general information: press/touch with index finger [23]
Select element and get its name:
index finger taps once/presses/touches the element [23]
Select sub-area of element and get its name:
index finger swipes on the area [23]
Get more information:
index finger swipes; tap/tap and hold with the index finger [23]
Record/retrieve notes: index finger taps twice [23]

Conclusion and Future Work

We examined gestures proposed by people with visual impairments reported by end-user elicitation studies. We found that 12 (4.8%) of the 249 GES/GES-related studies addressed users with visual impairments, of which only 4 studies (1.6%) actually reported gesture sets. We used the results of our analysis to compile a gesture-to-function vocabulary for smartphones, smart TVs, and tangible UIs.

While this vocabulary is useful to inform design of new gesture UIs, it also shows many lacunae, which need to be addressed by future work, such as regarding whole-body [24,25], and on-body gestures [34], free-hand gesture input [33], gestures for smart watches, smart rings [8], and smart glasses [21] as well as the need to explore a more diverse set of system functions beyond smartphones and TVs. While some of the gestures from Table 2 could be transferred to other contexts of use [32] (*e.g.*, touch gestures to smart watches with touchscreens; mid-air gestures to smart glasses with embedded video cameras and to rings with embedded motion sensors), conducting actual GES studies for these devices and contexts of use is recommendable. More studies are also recommended to compare the gesture preferences of users with and without visual impairments via between-subjects experiments [27] or that use other methods [1,18,31]. Consolidation of the vocabulary from Table 2 with replications [37] is equally needed. We hope that our focused survey and structuring of current knowledge regarding the gestures defined by users with visual impairments will foster more research on accessible gesture-based UIs.

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