

Ability-Centered Examination of People with Motor Impairments’ Interaction with Television Towards More Accessible Smart Home Entertainment Environments

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Abstract. We report results from a study with 41 people with motor impairments to understand their preferences for suitable input modalities, matched to their specific motor abilities, to interact with television. We report high preferences for voice- and smartphone-based input over hand gestures, head gestures, and eye gaze input. We discuss our findings in connection to the characteristic features of Ambient Intelligent environments, WHO levels of body functionality and disability, and a taxonomy of motor abilities, and we draw implications for more accessible home entertainment environments for users with motor impairments.

Keywords: Motor impairments · Smart home entertainment · AmI.

1 Introduction

Home entertainment, primarily represented by smart TVs, has known many advances in display technology [9], interactive content [17], communications [26], and input modalities [16, 18, 22]. In this context, Ambient Intelligence (AmI) environments [4] with their many quality properties—sensitive, responsive, adaptive, ubiquitous, transparent, and intelligent—can further enhance home entertainment experiences by centering on, adapting to, and anticipating users’ needs [1].

Intelligent adaptation, in particular, is essential to people with specific abilities to enable independent use of interactive systems. Prior studies [10, 23] have shown that people with motor impairments experience accessibility challenges when using conventional TV remote controls. For example, in Figure 1a, a person with Spinal Cord Injury (SCI) at vertebra C5 grasps the TV remote control with a specific hand pose, supports it against the chest, and applies pressure on the buttons with both arms; in Figure 1b, a person with SCI at C5 uses the TV remote control from the bed, a task that needs locating the remote without visual feedback, preventing its slipping, and using both hands to reposition the remote to press the buttons with the chin. The figure also enumerates specific motor abilities, e.g., arm movement, wrist rotation, bimanual coordination,



Fig. 1. Snapshots from videos collected during our study illustrating the use of TV remote controls under various motor abilities; see the text for descriptions.

etc., that are applied to use the conventional TV remote controls in a variety of situations.

Unfortunately, little is known about designing home entertainment systems that adapt to the specific motor abilities of the people who use them. Our practical contributions are: (1) We present results from a study with 41 people with motor impairments to understand preferences for TV input modalities matched to their motor abilities; our findings complement the results from [23] about accessibility challenges for TV input; (2) We draw implications for more accessible home entertainment systems by using AmI quality properties [4], WHO’s levels of body functioning and disability [30], and a taxonomy of motor abilities [7].

2 Related Work

Prior work has introduced many innovations in smart home entertainment, from smart TV features that enable communication and social TV watching at a distance [26] to entertainment experiences that scale at room level [9] with AR [15, 17]. For example, Audience Silhouettes [26] target viewers’ peripheral attention by displaying cues of audience kinesics at the bottom of the TV screen, and IllumiRoom [9] extends the presentation of content from the TV screen to the wall behind it to enable new video gaming experiences. Such systems can be characterized in the context of AmI environments by being sensitive, responsive, and transparent [4], while the connection they make between AmI and AR

has been highlighted [28]. We refer readers to Cook *et al.* [4] and Aarts and Encarnação [1] for overviews of AmI technology and applications.

Extensive work has been conducted to document the accessibility of interactive systems for people with motor impairments [11, 12, 14, 23–25], and accessible interaction techniques have been proposed for mouse input [6], mobile devices [2, 29], interactive surfaces [13], text entry [5], drawing [8], and wearable devices [19, 21]. Şiean *et al.* [20] overviewed assistive technology at the intersection of AmI and AR/MR. However, the accessibility of interacting with television has been little examined for people with motor impairments [10, 23] and, overall, users with disabilities have been little voiced in the scientific community of interactive media experiences [27]. Nevertheless, many accessibility challenges exist when interacting with television, and Ungurean and Vatavu [23] reported that people with motor impairments spend significantly more time watching television than people without impairments. In this context, it is important to understand and document user preferences and needs for suitable input modalities for interactive smart television and home entertainment systems, matched to specific motor abilities, for unrestricted access to the interactive experiences delivered by those systems. Our study, described next, addresses this need.

3 Study

We conducted interviews with people with motor impairments to elicit their preferences for TV input modalities matched to their motor abilities. Our results complement the findings from [23] about accessibility challenges for TV input.

3.1 Participants

We interviewed 41 people with various motor impairments aged between 10 and 72 years old ($M=42.2$, $SD=13.6$ years, normally distributed values according to a Shapiro-Wilk test, $W=.987$, $p=.922$).¹ The main cause of motor disability in our sample was Spinal Cord Injury (SCI), reported by 65.9% of the participants. Other conditions included Cerebral Palsy, Muscular Dystrophy, and Traumatic Brain Injury; see Table 1 and [23] for more details.

3.2 Motor abilities

We center our scientific examination on the relationship between motor abilities and preferences for input modalities for smart TVs. To this end, we employ a taxonomy from Fleishman [7], who identified 11 psychomotor factors that account for the variance of human performance on a wide range of tasks: (1) control precision, (2) multilimb coordination, (3) response orientation, (4) reaction time, (5) speed of arm movement, (6) rate control, (7) manual dexterity, (8) finger

¹ Two participants were under 18 years old. The responses of P₅ were entered by her father (online survey) and P₂₂ was accompanied by a parent during the interview.

Table 1. Participants’ demographics, self-reported impairments, and use of TV.

Participant (age, gender)	Health condition [†]	Self-reported impairments [‡]											Cus- tom RC	TV functions [§]						Assis- tance needed
		1	2	3	4	5	6	7	8	9	10	11		O	C	V	T	I	S	
P ₁ (54 yrs., M)	SCI (C5)	.	♦	.	.	♦	.	♦	♦	♦	♦	♦	.	.	♦	♦	.	.	.	.
P ₂ (37 yrs., M)	SCI (C4,C5)	.	♦	♦	.	.	.	.	.	.	.	.	.	.	♦	♦	.	.	.	.
P ₃ (46 yrs., M)	SCI (C5,C6)	.	.	.	.	.	.	♦	.	♦	.	.	.	.	♦	♦	.	♦	.	.
P ₄ (23 yrs., F)	SCI (C6)	.	.	.	.	.	.	♦	.	.	.	.	.	.	♦	♦	.	.	.	.
P ₅ (10 yrs., F)	MD	♦	.	♦	.	♦	♦	♦	♦	♦	♦	♦	♦	.	♦	♦	.	.	.	.
P ₆ (41 yrs., M)	TBI	.	.	.	.	.	.	♦	♦	.	.	.	.	.	♦	♦	♦	.	.	.
P ₇ (28 yrs., M)	SCI (C5,C6)	♦	.	♦	.	.	♦	♦	♦	♦	♦	♦	.	.	♦	♦	♦	♦	♦	♦
P ₈ (35 yrs., M)	SCI (C4,C5)	♦	♦	♦	.	.	.	.	.	.	.	.	.	.	♦	♦	♦	.	.	.
P ₉ (38 yrs., M)	SCI (C4,C5)	♦	♦	♦	.	.	.	.	.	.	.	.	.	.	♦	♦	♦	.	.	.
P ₁₀ (34 yrs., M)	SCI (C5)	♦	♦	♦	.	.	.	.	.	.	.	.	.	.	♦	♦	♦	.	.	.
P ₁₁ (47 yrs., F)	SCI (C5,C6)	.	.	.	.	.	.	♦	♦	.	.	.	.	.	♦	♦	♦	.	.	.
P ₁₂ (34 yrs., F)	Ataxia	♦	.	♦	.	.	.	♦	.	.	.	.	.	.	♦	♦	.	.	.	.
P ₁₃ (65 yrs., M)	SCI (C6)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	♦	.	.	.
P ₁₄ (35 yrs., M)	Cerebral Palsy	.	♦	♦	.	.	.	.	.	.	.	.	.	.	.	♦	.	.	.	.
P ₁₅ (72 yrs., F)	Ataxia	.	.	.	.	♦	♦	.	.	.	.	.	.	.	♦	♦	.	.	.	.
P ₁₆ (38 yrs., M)	Ataxia	♦	.	.	.	♦	♦	.	.	.	.	.	.	.	♦	♦	.	♦	.	.
P ₁₇ (54 yrs., M)	SCI (C5)	.	♦	.	.	.	.	♦	.	.	.	.	.	.	♦	♦	.	.	.	.
P ₁₈ (34 yrs., F)	Ataxia	♦	.	.	.	.	.	♦	.	.	.	.	.	.	♦	♦	.	.	.	♦
P ₁₉ (54 yrs., M)	TBI	♦	♦	♦	.	♦	♦	♦	♦	♦	♦	♦	.	.	.	.	.	.	.	♦
P ₂₀ (43 yrs., M)	SCI (C6)	.	♦	♦	.	♦	♦	♦	♦	♦	♦	♦	.	.	♦	♦	.	.	.	.
P ₂₁ (45 yrs., M)	SCI (C6)	.	.	♦	.	.	.	♦	♦	♦	♦	♦	.	.	♦	♦	.	.	.	.
P ₂₂ (15 yrs., F)	SCI (C6)	♦	♦	♦	.	♦	.	♦	♦	♦	♦	♦	.	.	♦	♦	.	.	.	.
P ₂₃ (41 yrs., M)	SCI (C6,C7)	.	.	♦	.	♦	♦	♦	♦	.	.	.	♦	.	♦	.	♦	.	.	.
P ₂₄ (55 yrs., M)	SCI (C5,C6)	♦	♦	♦	.	♦	♦	♦	♦	♦	♦	♦	.	.	♦	.	.	.	.	♦
P ₂₅ (49 yrs., M)	SCI (C3,C4)	♦	♦	♦	.	♦	♦	♦	♦	♦	♦	♦	.	.	♦	♦	♦	♦	♦	♦
P ₂₆ (20 yrs., M)	SCI (C7)	.	.	.	.	.	.	.	♦	.	♦	.	.	.	♦	♦	.	.	.	.
P ₂₇ (24 yrs., F)	SCI (C5,C6)	.	.	♦	.	♦	♦	♦	♦	♦	♦	♦	.	.	♦	♦	.	.	.	.
P ₂₈ (63 yrs., M)	SCI (C2,C3)	.	.	♦	.	♦	♦	♦	♦	♦	♦	♦	.	.	♦	♦	.	.	.	♦
P ₂₉ (24 yrs., M)	SCI (C5)	♦	.	♦	.	.	.	.	♦	.	.	.	.	.	♦	♦	.	.	.	.
P ₃₀ (51 yrs., M)	SCI (C5,C6)	♦	.	♦	.	.	.	♦	.	.	.	.	.	.	♦	♦	.	.	.	.
P ₃₁ (46 yrs., M)	Cerebral Palsy	♦	♦	♦	♦	.	♦	♦	♦	♦	♦	♦	.	.	.	.	.	.	.	♦
P ₃₂ (43 yrs., M)	SCI (C6)	.	.	.	.	♦	.	♦	♦	♦	♦	♦	.	.	♦	♦	.	.	.	.
P ₃₃ (42 yrs., M)	SCI (C6,C7)	.	.	.	.	.	.	♦	♦	♦	♦	♦	.	.	♦	♦	.	♦	.	.
P ₃₄ (55 yrs., M)	SCI (C6,C7)	♦	.	♦	.	♦	.	.	.	.	.	.	.	.	♦	♦	.	.	.	.
P ₃₅ (45 yrs., M)	SCI (C3,C4)	♦	♦	.	.	♦	.	♦	♦	♦	♦	♦	♦	.	♦	♦	.	.	.	.
P ₃₆ (57 yrs., M)	Cerebral Palsy	♦	♦	.	.	.	.	.	.	.	.	.	.	.	♦	♦	.	.	.	.
P ₃₇ (36 yrs., F)	SMA 3	♦	.	.	.	.	♦	♦	.	.	.	.	♦	.	♦	♦	.	.	♦	.
P ₃₈ (62 yrs., F)	Brain aneurysm	♦	♦	♦	♦	♦	♦	.	♦	.	♦	.	.	.	♦	♦	.	.	.	♦
P ₃₉ (43 yrs., M)	SCI (C6)	.	♦	.	.	.	.	♦	♦	♦	♦	♦	.	.	♦	♦	.	.	♦	.
P ₄₀ (50 yrs., F)	Cerebral anoxia	♦	.	.	.	♦	.	.	♦	.	.	.	.	.	♦	♦	.	.	.	.
P ₄₁ (42 yrs., F)	Cerebral Palsy	♦	♦	.	.	♦	.	.	.	.	.	.	.	.	♦	♦	.	.	.	.
Summary		22	18	22	2	28	20	31	28	15	27	23	5	9	39	35	5	4	4	9

[†]SCI=Spinal Cord Injury; TBI=Traumatic Brain Injury; MD=Muscular Dystrophy; The code in the parentheses denotes the affected vertebra(e), e.g., C4=the fourth cervical vertebra.

[‡]1=Slow movements; 2=Spasm; 3=Low strength; 4=Tremor; 5=Poor coordination; 6=Rapid fatigue; 7=Difficulty gripping; 8=Difficulty holding; 9=Lack of sensation; 10=Difficulty controlling direction; 11=Difficulty controlling distance; see [6].

[§]O=on/off; C=channels; V=volume; T=teletext; I=channel info; S=smart TV options.

dexterity, (9) arm-hand steadiness, (10) wrist/finger speed, (11) aiming. Table 2 connects abilities with the TV remote, the control condition in our study, against which we assess the perceived suitability of other input modalities; see next.

3.3 Measures

We collected the following information during our interviews:

- Assessment of the participants’ health and disability conditions using Findlater *et al.*’s [6] eleven categories of self-reported impairments; see Table 1.

Table 2. Motor abilities required to operate the TV remote control; see also Figure 1.

Task	Description	Required motor abilities	Correspondence with [7]
Reach	Reach for the RC	Move the arm	(1) control precision
Grasp	Pick up and seize the RC	Control the wrist, move the fingers, apply force	(7) manual dexterity
Hold	Hold the RC steadily	Apply continuous force	manual dexterity
Point	Point the RC at the TV	Move the arm, control the wrist	(1) control precision, (9) arm-hand steadiness
Press	Press buttons on the RC	Apply force, move fingers	(8) finger dexterity, (11) aiming

- Information about frequently used TV functions.
- Information about assistance needed for TV watching and control.
- Elicitation of preferences for input modalities for the TV, including *smartphone*, *voice*, *hand gestures*, *head gestures*, *eye gaze*, and *TV remote control*; the latter represents our control condition. These categories were informed by prior work that examined head gestures [2] and eye gaze [5] for users with motor impairments, smart TV models featuring voice [16] and hand gesture [18, 22] input, and prior work [11, 29] that reported effective smartphone use by people with motor impairments. Participants provided ratings for each condition using 5-point Likert scales: 1 (“not suitable at all”), 2 (“little suited”), 3 (“moderately suited”), 4 (“suited”), and 5 (“very suited”).

4 Results

We found a large number ($N=236$) and a diversity ($SD=8.03$) of self-reported motor impairments, among which the most frequent were *difficulty gripping* (75.6%), *poor coordination* (68.3%), *difficulty holding* (68.3%), and *difficulty controlling direction* (65.9%); see Table 1. These impairments have a direct impact on the use of conventional TV remote controls that require gripping, holding, and pointing; see Table 2. We also found that the most frequently employed TV functions were changing channels (95.1%), adjusting volume (85.4%), and turning on/off the TV screen (22.0%). Corroborated, these findings suggest that simple designs of TV remote controls with only a few buttons might be more accessible. However, even if such solutions are commercially available, prior work [23] has reported little adoption. For example, five of our participants (12.2%) reported having used custom TV remote controls, but also mentioned the shortcomings of such solutions, including high prices. Also, a percent of 22.0% of our participants mentioned the need of assistance to control the TV.

Figure 2 shows participants’ mean ratings of the six input modalities for TV control examined in our study. Overall, voice, smartphone, and TV remote control scored higher ($Mdn=4$, $M \geq 3.2$) than hand, head gestures, and eye gaze ($Mdn \leq 2$, $M \leq 2.2$). Figure 3 shows the relationships between self-reported motor impairments and the perceived suitability of input modalities: on the left, the average suitability ratings are illustrated for each type of impairment; on the right, suitability ratings are shown for the cases where participants did not report a specific motor impairment. Several differences are visible, such as a higher preference for voice input and a preference for head gestures (Figure 3, left)

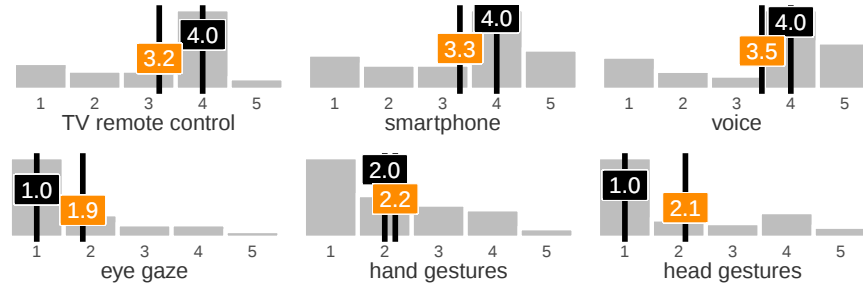


Fig. 2. Perceived suitability of input modalities for TV control. *Notes:* means are shown in orange, medians in black; larger values indicate better perceived suitability.

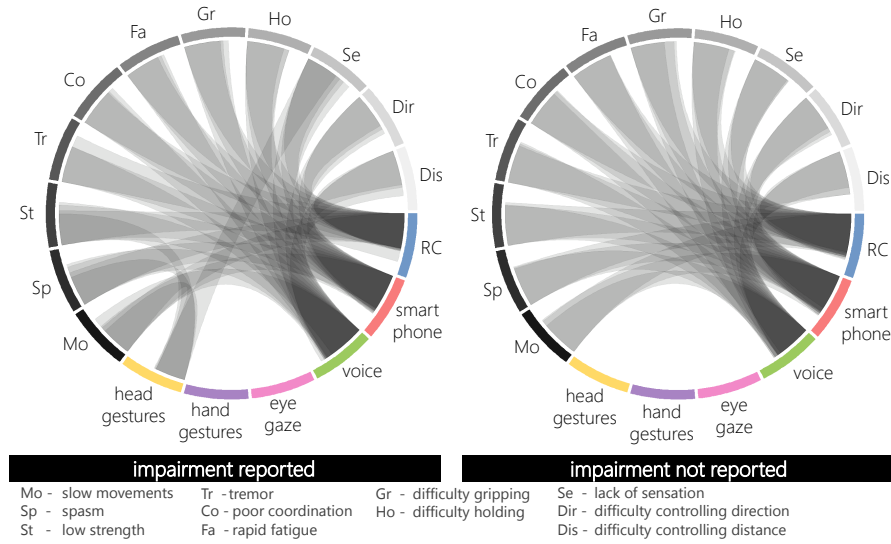


Fig. 3. The influence of specific motor impairments on the perceived suitability of TV input modalities. On the left, average suitability ratings computed for the participants that reported a specific impairment. On the right, average ratings when a specific impairment was not reported. *Note:* only arcs with average ratings above 2.5 are shown.

compared to the case where a specific impairment was not reported (Figure 3, right). To understand these differences better, Figure 4 shows radar charts with eleven dimensions according to each motor impairment category; see Table 1 for correspondences. We found higher suitability of voice (Mdn=4), smartphone (Mdn=4), and TV remote control (Mdn=4) over hand gestures (Mdn=2), head gestures (Mdn=1), and eye gaze (Mdn=1). We also found statistically significant positive correlations between TV remote control and smartphone (Spearman's $\rho_{(N=41)}=.332, p=.05$), between head gestures and eye gaze ($\rho_{(N=41)}=.687, p=.01$), and significant negative correlations between TV remote control and head gestures ($\rho_{(N=41)}=-.495, p=.01$), and between eye gaze and TV remote control ($\rho_{(N=41)}=-.438, p=.01$) and smartphone ($\rho_{(N=41)}=-.419, p=.01$).

Overall, we found that the absence of the *slow movements* motor impairment led to higher preferences for TV remote control (3.58 vs. 2.86), smartphone (3.68

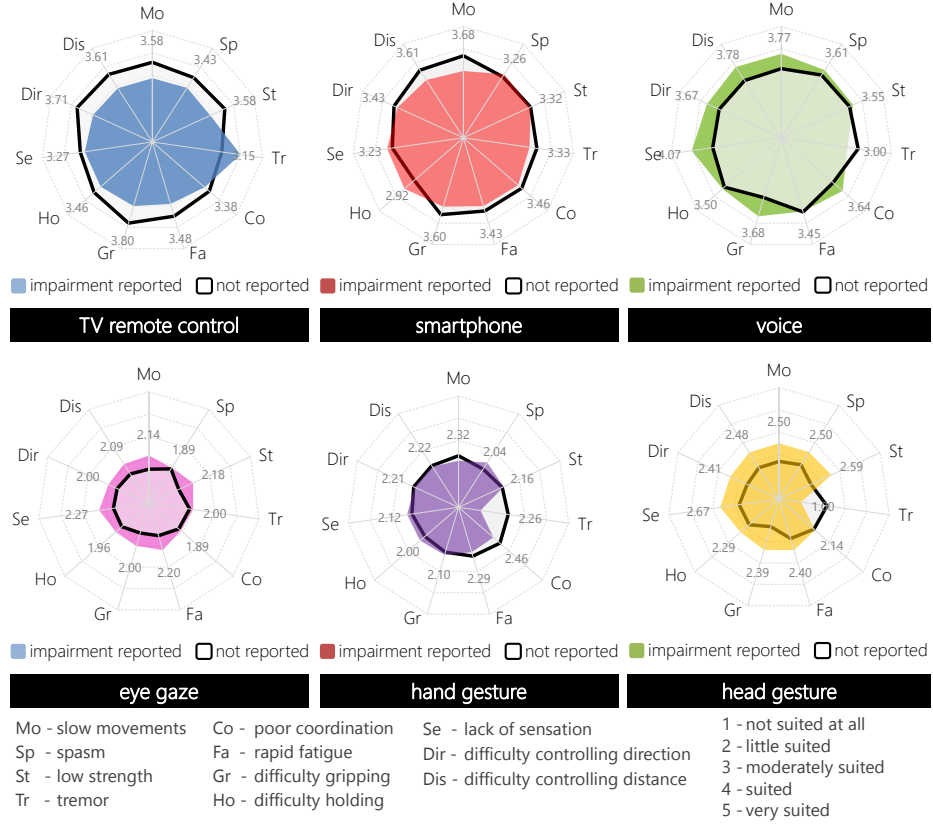


Fig. 4. Perceived suitability of the input modalities for TV control according to specific motor impairments. *Note:* larger values indicate better suitability.

vs. 3.00), and hand gestures (2.32 vs. 2.09), but not for voice, eye gaze, and head gestures; see Figure 4, top left. Also, the absence of *difficulty gripping* led to higher ratings of the TV remote control (3.80 vs. 3.00) and smartphone (3.60 vs. 3.23), but not of the other input modalities. We also found statistically significant correlations between the preference for hand gestures and the presence of *slow movements* (Kendall's $\tau_{(N=41)}=.307, p=.05$), *low strength* ($\tau_{(N=41)}=.313, p=.05$), and *difficulty gripping* ($\tau_{(N=41)}=.308, p=.05$), and between voice and *lack of sensation* ($\tau_{(N=41)}=.322, p=.05$). We capitalize on these empirical findings to discuss implications for more accessible smart TV systems; see next.

5 Discussion

We present implications of our findings for accessible home entertainment environments that center on the smart TV. To this end, we adopt three perspectives: (1) smart home entertainment as an instance of an AmI environment, for which we connect to the quality characteristics of AmI systems [1,4]; (2) the multilevel

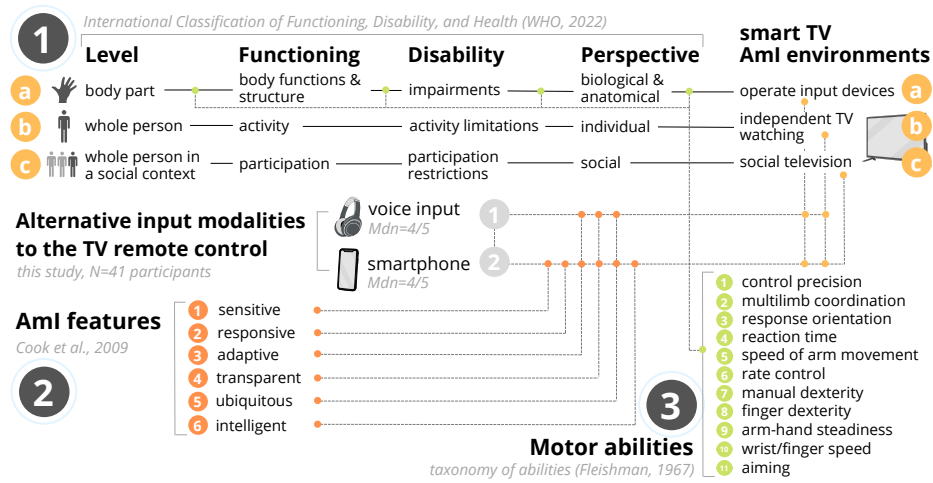


Fig. 5. Connections between body functioning and disability [30], AmI quality properties [4], and motor abilities [7] in the context of smart TV entertainment environments. *Note:* the small colored circles ●●● indicate connections between the various concepts.

relationship between body functioning and disability, for which we employ the biopsychosocial model [30] from the International Classification of Functioning, Disability, and Health; and (3) the relationship between users' motor abilities and their preferences for input modalities, for which we use Fleishman's [7] taxonomy (Subsection 3.2 and Table 2). Figure 5 illustrates these connections for the two highest-rated input modalities in our study, voice and smartphone input.

The experience of disability occurs at three levels of body functioning [30]: (a) at the level of a *body part*, where body structure and functions can be impaired; (b) at the level of the *whole person*, where activity limitations can occur; and (c) at the level of *the person in a social context*, where participation in life situations can be restricted; see Figure 5, top. Each of these levels correspond to different perspectives—biological, individual, and social,—for which specific tasks in a home entertainment environment centered on the smart TV can be identified: (a) input devices are operated at the *body part* level [10], (b) independent TV watching is an activity performed at the *whole person* level [23], and (c) social television watching [26] fosters active participation and involvement in a *social context*. The two highest rated input modalities in our study facilitate the connection between these tasks and AmI quality features; see Figure 5, middle and bottom left. For example, smartphones have been extensively examined for smart environments [3], where they act both as sensors and as information displays for the user. Also, voice input is increasingly present in the form of voice assistants in smart environments. Together, voice- and smartphone-based input enable interactions that fulfill the set of quality properties of AmI outlined by Cook et al. [4]. Figure 5, bottom right lists Fleishman's [7] motor abilities that connect to body functions and structure at the *body part* level, e.g., finger dexterity is reduced for people with SCI and affects use of specific input devices.

By capitalizing on the three perspectives—biological, individual, and social,—we propose several lines of future work for more accessible home entertainment environments for users with motor impairments: (i) interaction design that favors conjoint and interchangeable use of voice, smartphone, and TV remote control according to users’ specific motor abilities; (ii) design of smart TV interactions by adopting the quality properties of AmI as design requirements; (iii) flexible, adaptive input via user profiles consisting of self-reported motor impairments, specific motor abilities, and input preferences; and (iv) design for social TV watching to foster social participation.

6 Conclusion

We examined the relationship between specific motor abilities and users’ preferences for TV input modalities and found high perceived suitability of voice- and smartphone-based input, two input modalities compatible with voice assistants and smart mobile devices used as mediators of AmI interactions. Our findings complement prior work [23] about the accessibility challenges of TV remote controls with new results and corresponding implications for future work towards more accessible home entertainment environments centered on the smart TV.

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