Coping, Hacking, and DIY: Reframing the Accessibility of Interactions with Television for People with Motor Impairments

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ABSTRACT

We conduct an examination of the accessibility challenges experienced by people with upper body motor impairments when interacting with television. We report findings from a study with N=41 people with motor impairments (spinal cord injury, cerebral palsy, muscular dystrophy) and document their challenges and coping strategies for using the TV remote control, but also their television watching experience and expectations of suitable assistive technology for television. Our results show that, despite several accessible remote control products available on the market, the majority of our participants preferred to DIY and hack, and to adopt coping strategies to be able to use conventional TV remote controls. We contrast their experience against that of a control group with N=41 people without impairments. We reflect about the DIY culture and people with motor impairments, and we propose future work directions to increase the accessibility of interactions with television.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility technologies**.

KEYWORDS

Motor impairments; Television; Remote control; Study; Television experience; DIY; Coping strategies.

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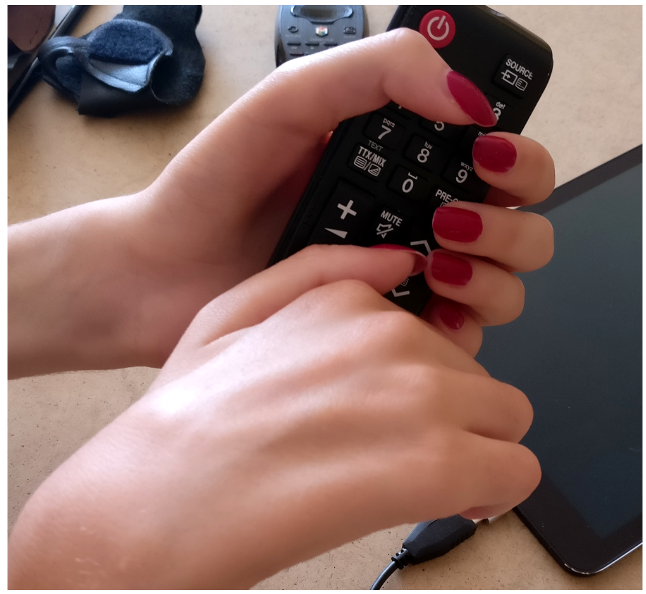

Figure 1: Using the TV remote control is a challenging task for people with upper body motor impairments. In this photo, a person with Spinal Cord Injury (SCI) at vertebrae C_5-C_6 presses a button on a conventional TV remote control.

1 INTRODUCTION

Watching television is an activity enjoyed by millions of people each day, mediated by one of the most ubiquitous input device worldwide, the TV remote control. Using the TV remote is so straightforward that people pay attention to it only when it turns out lost, the batteries need replacing, or the remote is in the temporary possession of someone else controlling it [9,29,95]. Despite recent innovations in interacting with television using voice [6,39], gestures [69,71,88,92], apps on smartphones [8], wearables [72,93], room-level motion tracking systems [76], AR devices [78], and on-skin input [26], the TV remote control is still prevalent and very actual.

However, using the remote control can be a challenging task for people with upper body motor impairments, for which the "simple" actions of reaching for the remote control, grabbing it, holding the remote in a stable position with a firm grasp, pointing it in the direction of the TV, reaching for the intended button to press, and exerting pressure to press buttons can be exhausting, if not impossible at all. Figure 1 shows a person with Spinal Cord Injury (SCI) located at vertebrae C_5-C_6 operating a conventional TV remote control. Notice the grip style, the need for two hands to hold the remote control and to reach for the button, and the way the button is pressed by exerting pressure using the lateral side of the thumb, an action leveraged by the movement of the upper arm and the weight of the hand.

Despite such accessibility problems and the large body of work on assistive input for people with motor impairments for a variety of

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computing devices [30,41,55,61,63,91,105], accessibility challenges for television and smart TVs have been less studied. One reason may be the recent focus on input modalities designed to complement or replace the TV remote control, such as gesture and voice input incorporated by many TV manufacturers into their products [52,79,80]. However, the motor abilities required to perform pointing gestures might be limited for some cases of motor impairments, while voice input might not be feasible where the motor impairments have induced functional changes in the respiratory system and, thus, affected speech production [10]. Another reason for the little attention of the community on the accessibility of television for viewers with motor impairments may lie with the fact that several accessible remote controls have been made commercially available [1,12,24,25,32], and their mere availability may induce the perception that television accessibility is no longer an issue. However, prior work [47,68] showed that a large percentage of assistive devices end up unused or abandoned. Moreover, we show in this work that people with motor impairments do not use such custom remotes, but instead prefer to engage in innovative DIY workarounds and invent coping strategies to be able to use the conventional remote controls that came with their TV sets.

In the light of these considerations, our work contours a new perspective for understanding how people with upper body motor impairments interact with television with a mix of coping, hacking, and DIY workarounds. This perspective enables us to report new discoveries, such as workarounds and coping strategies to deal with the accessibility problems of interacting with television, but also offers us the vantage point from which to reflect on television accessibility and to propose future work directions to increase it. The practical contributions of our work are as follows:

(1) We conduct a study with N=41 participants with upper body motor impairments of diverse causes (SCI, cerebral palsy, congenital muscular dystrophy, etc.) to document their accessibility challenges for interacting with television, but also their perceptions of the television watching experience and their expectations for accessible technology for future designs of smart TV products. We contrast their responses with those collected from a control group composed of N=41 people without motor impairments. For example, our results reveal that people with motor impairments spend twice as much time watching television than people without impairments, use second-screening just as much, yet they deal with many television accessibility problems, for which they invent workarounds and adopt coping strategies.
(2) We use our findings to propose a set of research directions involving smartphone apps, wearables, one-button devices, studies at the intersection of television experience and the DIY culture to foster new developments to increase television accessibility for people with motor impairments.

2 RELATED WORK

We discuss in this section prior work on designing assistive technology for users with motor impairments, including studies conducted to understand accessibility challenges. We also connect to work from interactive TV, such as input devices and techniques for novel TV experiences and studies reporting on viewers' television watching behavior, such as second-screening. Finally, we are interested in the DIY and making culture, for which we show that only few works have explored DIY involving people with motor impairments, while no work has addressed so far accessible fabrication of devices and/or smart TV apps to assist television watching.

2.1 Assistive Input Technology for Users with Motor Impairments

An extensive literature exists on assistive technology for users with motor impairments and a variety of computing devices, from desktop PCs [30,31] to tabletops [61], mobile devices [49,60,63,105], and wearables [55–57]. This literature has reported user performance with a wide range of input modalities, from touch input [31,38,61] to gesture [13,85,91], voice [18,40,41], eye gaze [16,46,70,102,103], and brain-computer input [28,62]. To mention a few examples, Smart Touch [61] is an accurate template matching technique designed to improve the performance of users with upper body motor impairments when selecting targets on touchscreens; Programming by Voice [40] is an interface that enables users with motor impairments to operate programming environments by speaking the code instead of using the mouse and keyboard; and EyeWrite [46] is a technique designed for eye-based text entry using letter-like gestures [100]. Such prior developments have been possible by means of careful analysis and understanding of the accessibility problems encountered by people with motor impairments in the physical world; see Anthony *et al.* [5], Kane *et al.* [49], Naftali and Findlater [63], and Mott *et al.* [60] for examples of studies unveiling accessibility issues, interaction challenges, coping strategies, and adaptations adopted by people with motor impairments to use input devices and user interfaces. Regarding input on mobile devices with touchscreens, Vatavu and Ungurean [91] released the largest dataset of stroke gestures collected from users with motor impairments, with which they reported results regarding user performance (e.g., production time) and system performance (e.g., gesture recognition accuracy).

2.2 Television Watching

In this work, we equally touch on aspects regarding people's television watching behavior, such as the number of hours dedicated to the TV per day or second-screening practices in order to better understanding the context in which people with motor impairments watch television. The use of second-screen apps, which enable viewers to interact with each other while watching television or to follow additional content related to the broadcast [7,22,48], has been documented for generic audiences [15,21]. Complementing television watching with mobile apps offers users more control, an enriched experience, and the possibility to express oneself and be part of a community [15]. Social television and television-mediated interpersonal communication have been supported by many modalities, such as text, audio, voice chats, emoticons, and avatars; see Amigo-TV [17], CollaboraTV [65], Social TV [42], and Audience Silhouettes [89] for examples of systems that combine broadcast television with interpersonal communication. Recently, Augmented Reality TV (ARTV) [73,75,90] has started to receive increased interest in the interactive TV community as AR technology has matured, while a research agenda exists to make ARTV more accessible to viewers with disabilities [74]. Nevertheless, studies of the television watching behavior of viewers with upper body motor impairments are yet to be conducted and smart TV apps informed by such studies are yet to be designed and implemented.

2.3 Television Control

Prior work has proposed a variety of input devices and techniques to interact with television, such as voice [6,39], gestures [69,77,88,92], wearables [72,93], and on-skin input [26], to mention a few examples. Also, several mobile applications are available to control the TV from the smartphone,[1] and using secondary screens during television watching has been an active area of research [7,15,21,22]. However, the designs from this prior work have assumed the motor abilities of people without motor impairments and, thus, little knowledge exists on how these interaction techniques, user interfaces, and applications can be used, if at all, by people with motor impairments. Actually, television control for people with various motor abilities has been little examined overall [59] compared to the attention dedicated to people with visual impairments [19,20,27]. Regarding accessible remote controls, a number of products are commercially available. These remotes usually feature large buttons [1,25], few buttons [32,104], facilitate grip and button pressing [3], are designed to minimize button confusion [104], use Radio Frequency instead of Infrared to remove the need of pointing the remote control in the direction of the TV [12,54], feature voice-activated commands [2], or permit integration with switches, e.g., the RV Remote Module from Enabling Devices [24] features several jacks to plug in switches to control power, volume, and TV channel navigation. However, it is a known fact that a large percentage of purchased assistive devices end up unused or abandoned [68] because being little appropriate to the individual needs of people who buy them, while in some cases, these products are too expensive. (As we report in this paper, only a few of our participants actually acquired and used such products.) An alternative solution for people with motor impairments to gain access to assistive technology is represented by DIY approaches [47]; see next.

2.4 DIY, Hacking, and the Making Culture

Tanenbaum *et al.* [83] argue that the pleasure and utility experienced in DIY activities democratize design and manufacturing. The maker culture consisting of maker communities and fabrication tools has been characterized by its intrinsic playfulness [84], opportunities for collaboration and co-participation in design work [23], independence and empowerment [23], and an outlet for altruism and well-being [94]. Several tools exist to foster the culture of self fabrication: MakeAware [81], a set of design goals and prototype for situation awareness in a makerspace, Popfab [67], a portable multipurpose digital fabrication tool, or Plain2Fun [96], a fabrication pipeline to make plain objects interactive, are just a few examples. The making culture has equally covered assistive technology (AT). For instance, McDonald *et al.* [58] reported on the challenges and opportunities of 3D printing for modifying and making AT a better fit to patients. And Hofmann *et al.* [44] investigated clinical AT fabrication by working with expert fabricators, and recommended solutions to support adaptable fabrication and integration into client care. In this work, we report several inventive solutions adopted by people with upper body motor impairments to use the conventional TV remote control that fall at the intersection of coping strategies, hacking practices, and what we believe represents an emerging DIY culture. Our also findings support previous observations that many AT devices go abandoned [47,68], and further highlight the importance of DIY accessible solutions for television.

3 STUDY

We conducted a study to understand accessibility challenges experienced by people with upper body motor impairments when interacting with television. Our method was questionnaire administration, both online and in situ, depending on the health condition of each participant, followed by a debriefing session taking place face-to-face or on the phone.

3.1 Participants

We recruited 41 participants between 10 and 72 years old (M=42.2, SD=13.6 years, ages normally distributed, W=0.987, p=.922) from a local clinic specialized in motor rehabilitation. Twenty-nine (29) participants were male; see Table 1 for demographic details. We considered for our sample only people with both upper limbs affected by motor impairments and that had lived with the impairment for a period of at least one year so that they had had the time to adapt to their motor impairment and to create their own coping strategies to be able to interact with physical objects and devices. Participants' health, assessed using the WHODAS 2.0 instrument [98], revealed a wide range of scores[2] between 8.3 and 89.6 (M=48.0, SD=18.0, normally distributed, W=0.981, p=.703); see Figure 2, left. To analyze the data collected from participants with upper body motor impairments against a baseline condition, we also involved in our study 41 participants without impairments (M=42.0, SD = 11.7 years, ages normally distributed, W=0.963, p=.202, 22 male). The age and gender distributions were similar for the two groups: $t_{(80)} = -0.044$, p=.965 (age) and $\chi^2_{(1,N=82)}$=2.541, p=.111 (gender), respectively.

3.2 Task

Participants filled in an online Google Forms questionnaire that we provided by e-mail, or they were read the questions and their answers recorded by the experimenter during a phone or face-to-face conversation, depending on each participant's health condition. The questionnaire was self-administered by 19 participants with motor impairments, on the phone by the experimenter with 6 participants, and in situ for the rest of the 16 participants with motor impairments. Participants without impairments filled in the online questionnaire, except for two cases when the data was collected in situ. Our hybrid approach, mixing online questionnaires and interviews conducted on the phone and during face-to-face conversations, was motivated by our desire to collect data from a large

[1] For example, https://play.google.com/store/search?q=TVcontrol&c=apps or https://apps.apple.com/us/app/universal-remote-tv-smart/id1401880138.

[2] According to the general population norms released with WHODAS 2.0 [87, p. 44], the minimum score from our sample (8.3) corresponds to the 78th percentile (i.e., 78% of the general population score better), the mean score (48.0) corresponds to the 98th percentile, and the maximum score (89.6) positions between the 99.7th and 100th percentile. According to the normative data report of Andrews *et al.* [4] based on 8,841 respondents, individuals scoring between 20 and 100 are in the top 10% of the population distribution likely to have clinically significant disabilities.

Table 1: Demographic details of the participants with upper body motor impairments from our study, their self-reported impairments using the categories from Findlater *et al.* [30], and the corresponding WHODAS 2.0 health and disability scores [97].

Participant	Health condition‡	Since	Self-reported impairments†											WHODAS 2.0 score
			Mo	Sp	St	Tr	Co	Fa	Gr	Ho	Se	Dir	Dis	
P_1 (54 yrs., male)	Spinal Cord Injury (C5)	1997		✓			✓		✓	✓	✓	✓	✓	43.8
P_2 (37 yrs., male)	Spinal Cord Injury (C4,C5)	2002		✓	✓				✓	✓		✓		14.6
P_3 (46 yrs., male)	Spinal Cord Injury (C5,C6)	1995							✓		✓			52.1
P_4 (23 yrs., female)	Spinal Cord Injury (C6)	2008							✓					25.0
P_5 (10 yrs., female)	Congenital Muscular Dystrophy	2008	✓		✓		✓	✓	✓	✓		✓	✓	66.7
P_6 (41 yrs., male)	Traumatic Brain Injury	1996							✓	✓				29.2
P_7 (28 yrs., male)	Spinal Cord Injury (C5,C6)	2017	✓		✓			✓	✓	✓		✓		16.7
P_8 (35 yrs., male)	Spinal Cord Injury (C4,C5)	2015	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	60.4
P_9 (38 yrs., male)	Spinal Cord Injury (C4,C5)	2003	✓	✓	✓		✓	✓	✓	✓		✓	✓	41.7
P_{10} (34 yrs., male)	Spinal Cord Injury (C5)	2000	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	58.3
P_{11} (47 yrs., female)	Spinal Cord Injury (C5,C6)	2003							✓	✓				70.8
P_{12} (34 yrs., female)	Ataxia (Friedreich's)	1996	✓		✓			✓						31.3
P_{13} (65 yrs., male)	Spinal Cord Injury (C6)	2011							✓					56.3
P_{14} (35 yrs., male)	Cerebral Palsy	1983		✓	✓									47.9
P_{15} (72 yrs., female)	Ataxia	2013					✓	✓						33.3
P_{16} (38 yrs., male)	Ataxia (Friedreich's)	2002	✓				✓	✓				✓	✓	54.2
P_{17} (54 yrs., male)	Spinal Cord Injury (C5)	2017		✓			✓	✓		✓				35.4
P_{18} (34 yrs., female)	Friedreich's ataxia	1996	✓				✓		✓			✓	✓	47.9
P_{19} (54 yrs., male)	Traumatic Brain Injury	1996	✓	✓	✓		✓	✓	✓	✓		✓	✓	70.8
P_{20} (43 yrs., male)	Spinal Cord Injury (C6)	2003		✓	✓		✓	✓	✓	✓	✓	✓		37.5
P_{21} (45 yrs., male)	Spinal Cord Injury (C6)	2013			✓		✓	✓	✓	✓	✓	✓		35.4
P_{22} (15 yrs., female)	Spinal Cord Injury (C6)	2015	✓	✓	✓		✓		✓	✓	✓	✓	✓	45.8
P_{23} (41 yrs., male)	Spinal Cord Injury (C6,C7)	1998			✓		✓	✓	✓	✓			✓	43.8
P_{24} (55 yrs., male)	Spinal Cord Injury (C5,C6)	1998	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	60.4
P_{25} (49 yrs., male)	Spinal Cord Injury (C3,C4)	2004	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	47.9
P_{26} (20 yrs., male)	Spinal Cord Injury (C7)	2001								✓		✓		35.4
P_{27} (24 yrs., female)	Spinal Cord Injury (C5,C6)	2016			✓		✓	✓	✓	✓		✓		43.8
P_{28} (63 yrs., male)	Spinal Cord Injury (C2,C3)	1999			✓		✓	✓	✓	✓	✓	✓	✓	66.7
P_{29} (24 yrs., male)	Spinal Cord Injury (C5)	2010	✓		✓		✓		✓	✓		✓	✓	58.3
P_{30} (51 yrs., male)	Spinal Cord Injury (C5,C6)	1992	✓		✓				✓		✓	✓	✓	54.2
P_{31} (46 yrs., male)	Cerebral Palsy	1972	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	89.6
P_{32} (43 yrs., male)	Spinal Cord Injury (C6)	1999					✓		✓	✓	✓	✓	✓	43.8
P_{33} (42 yrs., male)	Spinal Cord Injury (C6,C7)	1996					✓		✓	✓		✓	✓	37.5
P_{34} (55 yrs., male)	Spinal Cord Injury (C6,C7)	1998	✓		✓		✓		✓			✓	✓	41.7
P_{35} (45 yrs., male)	Spinal Cord Injury (C3,C4)	1997	✓	✓			✓		✓	✓	✓	✓	✓	62.5
P_{36} (57 yrs., male)	Cerebral Palsy	1961	✓	✓									✓	8.3
P_{37} (36 yrs., female)	SMA 3	1985	✓					✓	✓				✓	47.9
P_{38} (62 yrs., female)	Brain aneurysm	2015	✓	✓	✓	✓	✓	✓		✓		✓		85.4
P_{39} (43 yrs., male)	Spinal Cord Injury (C6)	1998		✓			✓		✓	✓	✓	✓	✓	43.8
P_{40} (50 yrs., female)	Cerebral anoxia	2017	✓				✓			✓				83.3
P_{41} (42 yrs., female)	Cerebral Palsy	1976	✓	✓			✓							39.6
		Summary	**22**	**18**	**22**	**2**	**28**	**20**	**31**	**28**	**15**	**27**	**23**	**48.0**

†Mo = Slow movements; Sp = Spasm; St = Low strength; Tr = Tremor; Co = Poor coordination; Fa = Rapid fatigue; Gr = Difficulty gripping; Ho = Difficulty holding; Se = Lack of sensation; Dir = Difficulty controlling direction; Dis = difficulty controlling distance.
‡The code in the parentheses denotes the affected vertebra(e), e.g., "(C6)" refers to traumatic injury at the 6th cervical vertebra.
The responses of participant P_5 were entered by her father (online survey) and P_{22} was accompanied by one parent during the interview.

number of people with motor impairments, including people that could not self-administer the survey. The result of this hybrid approach to data collection was a large sample of 41 participants with motor impairments sharing their experience regarding television watching and interacting with television; see Table 1.

3.3 Measures

The questionnaire had four sections with measures informed from prior studies investigating accessibility challenges experienced by people with motor impairments with various computing technology [30,61] and from studies examining various aspects about viewers' television watching behavior [15,21,34,89], as follows.

3.3.1 Demographic information and health condition assessment. Participants with motor impairments provided details about their health condition and reported their motor impairments according to the following eleven categories from Findlater *et al.* [30]: *slow movements*, *spasm*, *low strength*, *tremor*, *poor coordination*, *rapid fatigue*, *difficulty gripping*, *difficulty holding*, *lack of sensation*, *difficulty controlling direction*, and *difficulty controlling distance*.

This section of the questionnaire also included the 12-item Disability Assessment Schedule 2.0 (WHODAS 2.0), a public domain, standardized, cross-cultural compatible assessment instrument for health and disability [98] developed by WHO according to the International Classification of Functioning, Disability, and Health [87].

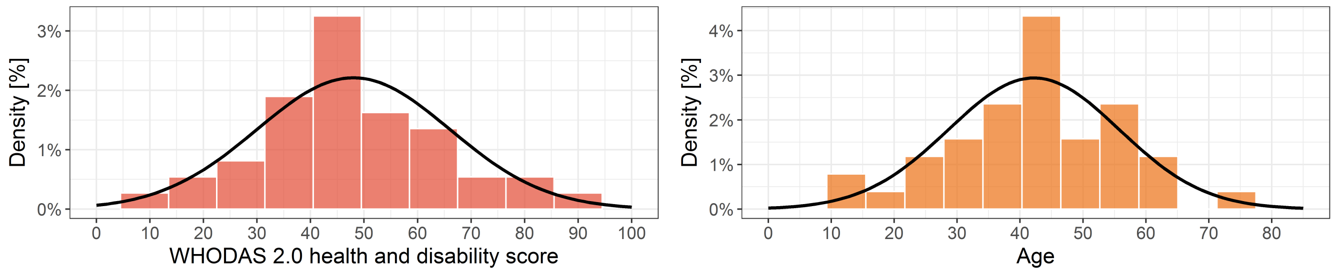

Figure 2: *Left:* Health and disability scores for participants with motor impairments, assessed with the WHODAS 2.0 instrument [97], show a normal distribution and a wide coverage (min 8.3 and max 89.6—higher values indicate advanced disability). *Right:* our participants' ages, normally distributed and covering a wide interval as well (min 10 and max 72 years).

WHODAS 2.0 computes a score between 0 (no disability) and 100 (full disability) that characterizes an individual's level of functioning on six levels: *cognition* (understanding and communicating), *mobility* (moving and getting around), *self-care* (attending to one's hygiene, dressing, eating, and staying alone), *getting along* (interacting with other people), *life activities* (e.g., domestic responsibilities, leisure, work, and school), and *participation* (e.g., joining community activities, participating in society); see [87] for details.

3.3.2 Television watching behavior. We collected information about our participants' TV watching practices with the following self-reported measures:

(1) TV-Hours, ratio variable, representing the amount of television watching, including broadcast television and online videos, shows, and channels, in hours per day.
(2) Custom-Remote, nominal variable with two conditions (yes and no), reporting the use of custom TV remote controls or other assistive input devices to interact with television.
(3) Second-Screen, nominal variable with two conditions (yes and no), reporting the use of smart mobile devices for second-screen television watching.

3.3.3 Accessibility challenges for interacting with television. We asked participants to describe their accessibility challenges with television. We also measured Perceived-Difficulty, ordinal variable, as a rating of the difficulty to use the TV remote control assessed with a 5-point Likert scale with items ranging from 1 to 5: *not difficult at all*, *slightly difficult*, *moderately difficult*, *difficult*, and *very difficult or impossible for me*. To understand the relative perceived difficulty of using the TV remote control compared to other input devices, we measured Perceived-Difficulty as a function of Input-Device, a nominal variable with five conditions: *mouse*, *keyboard*, *smartphone*, *tablet*, and *TV remote control*.

3.3.4 Perceived suitability of input modalities for interacting with television. We asked participants to rate the *TV remote control*, *smartphone*, *hand gestures*, *head gestures*, *eye gaze*, *voice input*, and *brain-computer input*, representing conditions of the Input-Modality variable, as suitable modalities for them to control the TV. To this end, we collected participants' responses using a 5-point Likert scale with items from 1 to 5: *not suited at all*, *little suited*, *moderately suited*, *suited*, and *very suited*.

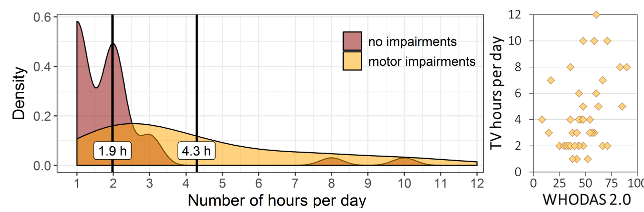

Figure 3: Density distributions of the TV-Hours variable for participants with and without motor impairments (left) and the relationship between TV-Hours and WHODAS 2.0 scores for participants with motor impairments (right).

4 RESULTS

We discuss in the following television accessibility challenges reported by people with upper body motor impairments, and contrast their perceptions and expectations of the television watching experience against the answers provided by the control group of participants without impairments.

4.1 Time Dedicated to Television Watching

Participants with motor impairments reported watching conventional television or following online videos and channels between 1 and 12 hours per day (M=4.3, SD=2.9 hours). In contrast, the average number of hours reported by participants without impairments was significantly lower (M=1.9, SD=1.8, $t_{(66.389)}$=4.426, p<.001, medium to large effect size, r=.477). Overall, participants with motor impairments reported spending twice as much time (+126%) watching television than participants without impairments; see Figure 3, left. We also found a statistically significant positive correlation between TV-Hours and the WHODAS 2.0 scores (Pearson's $r_{(N=41)}$=.379, p<.05): participants with more severe impairments were spending more hours watching television on a daily basis; see Figure 3, right. For example, participant P_{29} (SCI at vertebra C_5) reported watching TV for an average of ten hours each day, an activity during which *"finding the right button [on the TV remote control] is especially difficult because I'm always lying in bed and cannot see the buttons that I'm touching."* P_{24} (SCI C_5-C_6) reported watching twelve hours of television each day although using the TV remote control was impossible for him: *"I cannot move my fingers. I cannot use it [the TV remote control]. My assistant does it for me."*

Figure 4: Examples of custom devices to control the TV (a,b), DIY workarounds invented by participants with motor impairments (c,d,e), and coping strategies in the form of grip styles and hand poses (f,g,h,i) to be able to use the TV remote control.

4.2 Custom TV Remote Controls and Second-Screen Devices

We asked participants with motor impairments about any custom input devices they were using at the time of the study or had used in the past to interact with the TV. Only three participants answered affirmatively, reporting a power wheelchair joystick, a custom remote control specifically designed for people with disabilities, and a complex, general-purpose voice-based system designed to control various appliances, including the TV. For example, participant P_{35} (SCI, C_3-C_4) had been using various custom designed TV remote controls for about ten years. Their current remote control at the time of the study was a "GewaLink Control 18";[3] see Figure 4a. Just like other accessible remotes (see Section 2.3), the Control 18 features large buttons, works from a distance of up to 30 m, and is compatible with several accessories, such as a flexible mini-arm to attach the remote to a stable surface, key guards, and neck-straps. However, one downside remarked by P_{35} was *"the high price of custom remote controls and the need to set them up to work with a particular TV set model."* Participant P_{25} (SCI, C_3-C_4) reported using a dedicated voice-based system to control electrical appliances in his home, such as lights, heating, blindfolds, and the TV; see Figure 4b for a photo of the device. Because of his severe disability, P_{25} could perform movements of the head only: *"I can't use the TV remote control. My assistant does it for me. Or, I use voice commands."* However, his system, P_{25} said, was very expensive to purchase. The rest of the 38 participants with motor impairments (92.7%) reported using conventional TV remote controls.

Regarding second-screening, 17 participants with motor impairments (41.5%) and 14 without impairments (34.1%) reported using a mobile device, such as their smartphone, while watching television. A Chi-Square test of proportions did not detect any statistically significant effect of Motor-Impairment on the Second-Screen variable ($\chi^2_{(1,N=82)}$=0.254, p=.614, *n.s.*). The fact that smartphones are not just always available, but actually employed while watching TV by almost half of our participants with motor impairments has implications for designing assistive TV input techniques operated directly from the smartphone; see the Discussion section.

4.3 Self-Reported Accessibility Challenges

Table 2 lists accessibility challenges reported by participants with and without motor impairments when using the TV remote control, shown in descending order of their frequency. Participants with motor impairments focused almost exclusively on motor accessibility, such as the difficulty in gripping the TV remote control (reported by 26 participants, 63.4%), holding it stably (63.4%), pointing the remote in the direction of the TV (56.1%), pressing buttons on the remote (39.0%), and reaching for the TV remote control (24.4%). In the following, we discuss each of these challenges in detail.

4.3.1 Gripping and holding the TV remote control in a stable position. These two challenges were the most frequently reported by the participants with motor impairments (63.4%). For example, P_{33} (SCI C_6-C_7) remarked that *"the shape of the remote control makes it very*

[3] https://www.abilia.com/en/our-products/environmental-control/controllers/control-18

Table 2: Self reported accessibility problems. Notice the virtually no overlap between the problems reported by participants with and without motor impairments.

Reported problem	Participants *with* motor impairments Freq.	%	Participants *without* impairments Freq.	%
Gripping the remote	26	63.4%	-	-
Holding the remote	26	63.4%	-	-
Pointing the remote to the TV	23	56.1%	-	-
Pressing buttons on the remote	16	39.0%	-	-
Holding the remote	11	26.8%	-	-
Reaching for the TV remote	10	24.4%	-	-
TV remote impossible to use without assistance	10	24.4%	-	-
No difficulties[†]	3	7.3%	18	43.9%
Losing the TV remote control[‡]	1	2.4%	4	9.8%
Identifying button functions	-	-	8	19.5%
Too many buttons	-	-	6	14.6%
Buttons and/or space between buttons too small	-	-	3	7.3%
Batteries	-	-	2	4.9%
Typing text on smart TVs	-	-	2	4.9%
TV remote has no backlight	-	-	1	2.4%
Configuring channels	-	-	1	2.4%

[†] $\chi^2_{(1,N=82)}$=14.403, p<.001; ‡ $\chi^2_{(1,N=82)}$=1.917, p>.05, *n.s.*

slippery," P_1 (SCI C_5) said that *"finding the right position to hold the remote in order to press the buttons so that the remote does not slip from my hands is difficult,"* and P_2 (SCI C_4-C_5) had difficulties *"finding a stable position for the remote to be able to press the buttons."*

4.3.2 Reaching for the remote control and pointing it in the direction of the TV. Twenty-three of the participants with motor impairments (56.1%) mentioned this specific accessibility challenge. For example, P_9 (SCI C_4-C_5) reported: *"as a wheelchair user, if the remote is not near me at arm length, it is almost impossible to reach it. My family and friends are aware of this and they never leave the remote in places that I cannot reach."* P_9 also mentioned the coping strategy he devised in order to avoid pointing the remote to the TV: *"I have to use the remote with both hands and sometimes it is very difficult to point it to a surface that will reflect the infrared signal."*

4.3.3 Pressing the buttons on the TV remote control (39%). P_6 (traumatic brain injury) reported difficulties for *"moving from a button positioned at the top of the TV remote control to one at the bottom"* without having a surface to support the remote control on and, thus, to keep it in a stable position. P_{12} (Friedreich's Ataxia) found challenging to *"press two buttons in a fast sequence in order to jump to a particular channel, whose number has two digits."* P_{29} (SCI C_5) mentioned problems reaching for buttons, because *"I'm always lying in bed and cannot see the buttons that I'm touching."* Two participants (P_{27} and P_{30}, SCI C_5-C_6) reported having problems pressing buttons that were *"slippery,"* while P_1 (SCI C_5), P_{33} (SCI C_6-C_7), and P_{35} (SCI C_3-C_4) also characterized the TV remote as "slippery." This characterization was surprising to us at first, but the problem became evident when we realized that the materials from which buttons on remote controls are made of and the plastic used to fabricate remote cases vary among manufacturers.[4] (We encourage readers to think about the remote controls they have been using. Have you noticed any difference whatsoever in the materials from which the buttons on those remotes were made of? Actually, different manufacturers use different materials and the slightest difference, that usually goes unnoticed by a person without impairments, is important for a person with upper body motor impairments that wishes to use that remote control.)

4.3.4 The need for both hands. Twenty-three participants with motor impairments (56.1%) reported the need to use both hands to operate the TV remote control; see Figures 4f-i for photographs illustrating various hand poses and grip styles adopted, as coping strategies, to use conventional TV remote controls. For instance, P_7 (SCI C_5-C_6) reported: *"I use it [the remote control] with both hands and thumbs. I am not able to grip the remote and press buttons without effort and great difficulty."* Even participants that could operate the remote control with just one hand, such as P_{17} (SCI C_5) and P_{26} (SCI C_7), acknowledged that *"using it [the remote control] with one hand is very tiring"* and *"my right hand is stronger, but anyway I have to use it [the remote] with two hands."*

4.3.5 A stable surface to support the TV remote control. Eleven participants (26.8%) mentioned the need for a fixed, stable surface on which to position the TV remote control in order to be able to press its buttons without affecting the stability of the remote. For example, P_{23} (SCI C_6-C_7) was placing the TV remote control on a kitchen towel to prevent it from slipping or balancing on the table; see Figure 4c. (Balancing is caused by the fact that most remote controls have an "ergonomic" design for pleasant gripping with one hand represented by a rounded form factor for their backside.) P_{11} (SCI C_5-C_6) noted: *"As long I have it [the TV remote control] on a planar surface, I can use it,"* while wearing a hand strap (Figure 4d) further increased the precision of her button presses. P_8 (SCI C_4-C_5) commented *"placing it [the TV remote control on the table] is very difficult because it is designed to be used with one hand and not to be placed on my laps or on a surface as I am doing."* To deal with this aspect, P_8 had the TV remote control duck taped to a paper towel dispenser box to prevent it from slipping, sliding, and balancing; see Figure 4e. These findings show active preoccupation for accessible making with the conventional TV remote control as the starting point and, thus, coping strategies such as these can be characterized from a DIY perspective. Unlike strategies centered on the manipulation of the TV remote control (e.g., use two hands for a stable grip), the DIY approach is about using materials or surfaces to increase the accessibility of conventional TV remotes in new, creative ways. From this perspective, coping strategies for the TV remote control can be divided in two categories: those that do not physically modify or integrate the TV remote control into a better system for input (e.g., press the buttons repeatedly until successful, use two hands for a better grip, etc.), and those that show a preoccupation for what can be legitimately characterized as rudimentary, but nevertheless DIY-like approaches.

[4] The material used to make the buttons is a thermoplastic elastomer, of which there is a great variety; see Laurie Brenner, "Types of Plastic used to make TV remotes." Available at www.techwalla.com/articles/types-of-plastic-used-to-make-tv-remotes

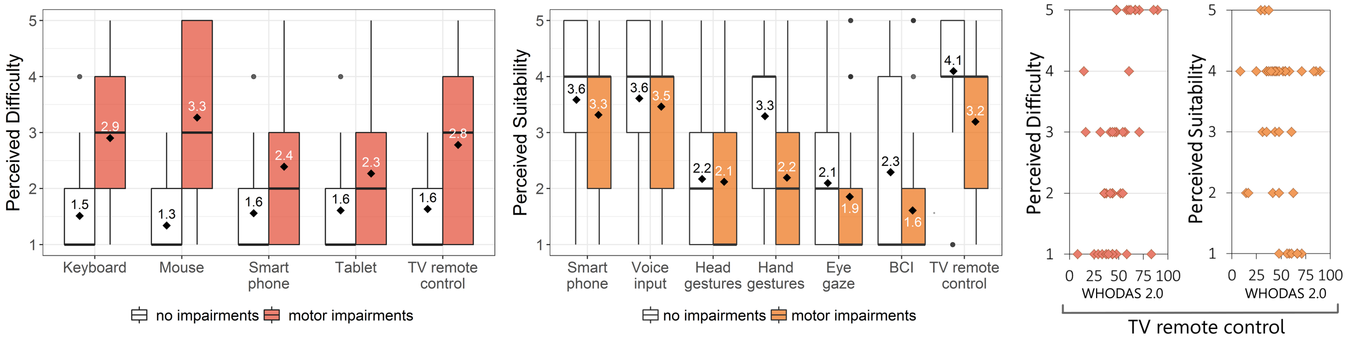

Figure 5: Box plots for the perceived difficulty and suitability of using the TV remote control compared to other input devices and modalities. *Notes:* horizontal bars show medians and diamonds indicate mean values; higher values denote more difficulty; the two scatter plots from the right show the relationship with the WHODAS score for participants with motor impairments.

4.3.6 Impossible to use the remote control independently. Ten participants (24.4%) reported that it was impossible for them to operate the conventional remote controls that their TV sets came with, and they always needed assistance from a family member. P_{10} (SCI C_5) said: *"unfortunately, I cannot grab the remote myself. If it is placed on my wheelchair arm, under my hand, I can use it, but I prefer to keep my smartphone there,"* and P_{24} (SCI C_5-C_6) commented: *"I cannot move my fingers. I cannot use it [the remote control]. My assistant does it for me."* Participant P_5 (congenital muscular dystrophy) was able to move their head and fingers only and someone else had to place the TV remote under her hand for her to be able to use it. Also, even if P_{35} (SCI C_3-C_4) was using a custom remote control (Figure 4a), someone else had to place it under his hand.

4.4 Participants without Motor Impairments

Table 2 also lists problems reported by participants without impairments for interacting with television, such as difficulties in pressing small buttons, which were found too many (14.6% of the responses) or pressing the wrong button or more buttons at once because the space between adjacent buttons was too small (7.3%). Other problems included the need to periodically replace batteries and finding the right button for a specific function because of button labels not being suggestive or intuitive enough. Interestingly, none of the problems mentioned by the participants without impairments were reported by participants with motor impairments, except for one case, losing the TV remote control, reported by P_{40} (cerebral anoxia). The challenges to grip, hold, point, and press buttons on the remote control seem to be so big that any other problems were not even mentioned by the participants with motor impairments.

4.5 Perceived Difficulty to Operate the Remote Control and the Suitability of Alternatives

We asked participants to rate the difficulty of using the TV remote control (and other input devices) and the suitability of the remote (and of other input modalities) to control the TV. A between-by-within ANOVA based on ranks using the Brunner *et al.* [11] non-parametric method implemented[5] by Wilcox [99, p. 423] showed a significant main effect of Motor-Impairment on Perceived-Difficulty (F=33.504, p<.001), no main effect of Input-Device (F=2.099, p=.09, *n.s.*), and a significant interaction between Motor-Impairment and Input-Device (F=9.532, p<.001); see Figure 5, left. The median rating of participants without impairments was 2 (slight difficulty), while the median rating of participants with motor impairments indicated moderate difficulty (3) for the TV remote control, keyboard, and mouse, and slight difficulty (2) for smartphones and tablets.

We also found a significant effect of Motor-Impairment on Perceived-Suitability (F=10.511, p<.001), a main significant effect of Input-Modality (F=33.223, p<.001), and a marginally significant interaction between Motor-Impairment and Input-Modality (F=2.291, p=.054); see Figure 5, middle. The remote control was appreciated as suitable (median rating 4) by both participants with and without motor impairments, although the mean ratings showed larger perceived suitability for participants without impairments (4.1 *vs.* 3.2). Two other modalities, smartphone and voice input, were rated equally (4) by participants with motor impairments. Hand and head gestures, eye gaze and, brain-computer input were perceived less suited (2) and not suited at all (1).

We found a significant positive correlation between the WHODAS 2.0 scores of health and disability and Perceived-Difficulty ratings for using the TV remote control (Spearman's r_s=.528, p<.01) and a negative linear correlation between WHODAS 2.0 and Perceived-Suitability ($r_s = -.365$, p<.05) as well as between Difficulty and Suitability ($r_s = -.810$, p<.01); see Figure 5, right. Participants with more severe impairments found the TV remote control more difficult to operate and less suited to control the TV, respectively.

5 DISCUSSION

Our results show that people with upper body motor impairments experience many accessibility challenges when interacting with television, for which they adopt coping strategies to use the conventional TV remote control, while only few buy and use custom remotes. We also found signs of DIY approaches to make the TV remote control more accessible and usable. Based on our findings, we propose five directions for future work to increase television accessibility for viewers with motor impairments.

[5] R function `bwrank` available from Rand Wilcox's web page at https://dornsife.usc.edu/labs/rwilcox/software/.

5.1 Smartphone input

Even if smartphones present accessibility problems of their own [50, 60,63], people with motor impairments do rely on their smartphones to avoid other accessibility challenges in the physical world. For instance, participant P_{10} (SCI C_5) reported that *"unfortunately, I cannot grab the TV remote control myself. If it is placed on the armrest of my wheelchair, under my hand, I can use it, but I prefer to keep my smartphone there."* Other researchers arrived at similar findings with people with motor impairments reported using their smartphones to control devices, including the TV, for which the accessibility problems were larger compared to the smartphone. To mention one example, a participant from Naftali and Findlater's [63] study about accessibility in context reported that he *"had his TV and stereo speakers connected to his iPhone so that he can remotely control the TV via voice commands and send it content. This means he does not have to use standard remote controls."* And Naftali [64] reported about a participant expressing their wish to control the TV and other devices from the living room using Siri from their smartphone.

Based on the observation that people with motor impairments rely on their smartphones to overcome other accessibility challenges in the physical world, the extensive research on making mobile devices more accessible [60,66,85,86,86,91], and research on second-screen television watching [15,21], we believe that designing accessible smartphone apps for interacting with television is a feasible alternative to conventional TV remote controls. Without being constrained by the form factor and button layouts of the TV remote control, more accessible designs can be implemented, such as large-area buttons, fewer buttons, and adaptive layouts to match users' motor abilities following the principles of ability-based design [101]; see the SUPPLE system [33] for a relevant example. To provide further support in this direction, we mention a comment from participant P_6 (traumatic brain injury), who reported difficulties *"moving from a button positioned at the top to one at the bottom of the remote control"* without having a surface on which to support the TV remote. Also, P_{12} (Friedreich's ataxia) reported difficulties in *"pressing two buttons in a fast sequence in order to jump to a particular channel, whose number has two digits."* Such accessibility problems would be easier to solve with an adaptive layout of soft buttons displayed on the smartphone's touchscreen.

5.2 From smartphones to smart wearables

Smartphones are attractive to replace TV remote controls as they provide stable input when placed on a surface, such as the armrest of the power wheelchair. However, they may not always be easy to reach. On the other hand, wearable devices are affixed to the body and can be interacted with concurrently and alongside input on smartphones and tablets, creating thus the premises for alternative input modalities or mixed input for controlling appliances in the home, the TV included, according to each user's preferences and motor abilities. Prior work has started looking at the usability of smart wearables, such as smartglasses [56] and smartwatches [55], and an opinion paper [35] discussed the opportunities of smart rings for people with upper body motor impairments.

A few examples are useful to present in the support of this research direction. Many of our participants reported that the form factor of the TV remote control makes the remote unstable, especially when placed on a supporting surface, such as a tabletop. An unstable remote, or a "slippery" remote as some of our participants described it, is also difficult to point at the TV, hold still, and press its buttons without affecting its orientation and stability in the hand. Having a wearable device attached to the finger (e.g., a smart ring), the wrist (a smartwatch or a fitness band), or the arm (a smart armband) can remove the problems of grabbing, gripping, and holding the TV remote control. However, it may also create other accessibility problems caused by the small form factors of such wearables, making the suitability of wearable devices that require finger and hand input to be dependent on the specific type and severity of the user's motor impairment.

AR glasses could also be used to address specific accessibility problems involving the TV remote control. For example, P_{29} (SCI C_5) mentioned their difficulty finding the intended button to press on the TV remote control because *"I'm always lying in bed and cannot see the buttons that I'm touching."* Providing feedback directly at eye level for users that cannot control their arms or head muscles could prove helpful in a variety of contexts of use involving the control of devices in the home, the TV included. Such research has been conducted for AR glasses and users with visual impairments to provide assistance during demanding visual search tasks [106] or navigation [45]. An agenda proposed for the visual augmentation of the television experience [74] has discussed the needs of viewers with visual impairments, but neglected to consider those of viewers with motor impairments. However, a recent conceptualization of AR for television [90] has specifically mentioned ARTV accessibility for people with disabilities as an important direction for the future of accessible home entertainment.

5.3 One-button input

Many input devices, from remote controls to keyboards, smartphones, and the ubiquitous computer mouse, feature at least one physical button. Although one button with just two states may not seem as much, prior work has shown how even complex tasks can be performed with one button only with proper interaction design. A special genre of computer games known as "one-button games" [37] enables users to perform complex interactions with mere presses of a single button. For example, Miami Street [36], a car racing video game, is played with mouse clicks only by following the on-screen instructions, such as "hold left mouse to accelerate" or "release to break." The corresponding concept of a microswitch [82] has been implemented with a variety of input modalities, sensors, and devices to deliver assistive technology for people with motor impairments. For example, Lancioni *et al.* [51] documented the case of two people with severe post-comma motor impairments and showed how they benefited from microswitch assistive technology. Thus, exploring one-button input techniques for controlling devices in the home, the TV included, represents an interesting direction for future work. This direction may include new input devices specifically designed to afford simple and ergonomic one-button input. The button could be located on the armrest of the power wheelchair in line with chairable technology [14] or on a smart wearable [35] that is easy to reach and press. A caveat, however, is represented by the low speed of one-button input for complex tasks and, thus, interaction techniques that enable users to express a variety of intents and to effect commands using one button only, but that are also fast enough according to the specifics of the task and context of use, are needed.

5.4 Television watching behavior

In this work, we have focused on the accessibility challenges for interacting with television, but we have also touched on aspects regarding television watching. However, more research is needed, including longitudinal observational studies, to understand better television watching for people with motor impairments. Such studies will inform the design of new applications for smart TVs adapted to the way viewers with motor impairments watch television.

To understand the importance of and need for such work, we present a few examples. For instance, researchers have found that people develop different watching strategies to follow content on television, e.g., some people look at the TV from time to time, just enough to be aware of what is happening, while engaged in other activity. In fact, most looks at the TV can be described as mere glances lasting two seconds at most [43]. The "hazard function," introduced by Hawkins *et al.* [43], models the probability that looks at the TV persisting a given duration will terminate in the next half second. Using this model, television watching strategies can be described in terms of *monitoring looks* (frequent, but short in duration, lasting less than 1.5 seconds), *orienting looks* (up to 5 seconds), *engaged looks* (between 6 and 15 seconds), and *staring*, which occurs after 15 seconds of uninterrupted attention to the TV [43]. Short looks especially are part of a common behavior known as "zapping," i.e., the practice of quickly scanning through different channels in the search of interesting content to watch. An interesting fact is that the zapping behavior can be analyzed in order to generate more accurate channel recommendations for viewers [53]. However, zapping is likely a rare behavior in the case of people with upper body motor impairments because of their accessibility problems in pressing buttons on the TV remote control. Unfortunately, the lack of research in this direction limits our current understanding of the television watching behavior of viewers with motor impairments, which impacts negatively the design of recommender systems for smart TV applications.

5.5 DIY and the Maker Culture

The maker culture is grounded in democratizing design and manufacturing [83] with many benefits for product consumers, among which the opportunity for collaboration, independence, empowerment, altruism, and well-being have been highlighted by prior work [23,84,94]. In our study, we observed an interest for DIY approaches, where participants with motor impairments crafted their own practical solutions by exploring materials, surfaces, and objects from their environment, which they incorporated into practical workarounds to be able to operate the conventional TV remote control. Noteworthy, the DIY approach contrasts the coping strategies that we have also observed and documented in our study, such as the specific ways to grip and hold the TV remote control or to press its buttons. Moreover, the participants with motor impairments preferred DIY and continued using coping strategies in the detriment of buying off-the-shelf accessible remote control products that were either too expensive or not tailored to their needs and, thus, little useful. In this context, we believe that the maker culture needs to be encouraged for people with motor impairments and fostered with accessible fabrication tools. Such a direction will lead to input devices for interacting with television that are more accessible and usable than originally thought by expert product designers, but also to applications for smart TVs and second-screening that adapt better to their viewers through the benefits of personalization and reappropriation. On the long term, accessible making is expected to have a positive impact in terms of independence and empowerment [23]. From this perspective, more studies are needed in this direction to further surface the details and characteristics of this practice that has been little documented.

6 CONCLUSION

We revisited in this work the accessibility challenges of people with upper body motor impairments for interacting with television and documented their coping strategies and DIY workarounds. We used our findings to outline a set of research directions regarding accessible input techniques, devices, and TV apps grounded in a better understanding of the television watching experience for people with motor impairments. Our paper is equally a manifest to draw the attention of the assistive technology and interactive television communities that more work is needed to make the ubiquitous activity of television watching a more enjoyable experience for people with upper body motor impairments. We hope that further research and practical developments will follow.

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