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THEME ARTICLE: LIFE AND WORK AT HOME

Co-Designing Accessible Computer and Smartphone Input Using Physical Computing

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Significant obstacles persist in meeting the accessibility needs of computer and smartphone users with mild-to-moderate upper limb motor impairments as they use their devices at work and home. Multimodal input can help, but has not been widely adopted. We build on existing literature with a discovery survey and semistructured follow-up interviews in which we identify common themes related to the limitations of today's solutions and the ad hoc workarounds which are adopted. We ran a series of co-design workshop sessions to understand the potential of modern "physical computing" electronic device prototyping technologies to provide new and effective input options for our target user base. We present the resulting prototype solutions and describe the technology choices made. Finally, we discuss how the co-design process, in conjunction with access to suitable physical prototyping technologies, can be a powerful approach for designing accessibility-focused input systems.

There has been a significant effort among human–computer interaction (HCI) researchers to develop more accessible alternatives to computer and smartphone input. Lowering the access barriers to these digital technologies would make a positive impact socially and economically. Recent research has shown that the number of people with motor impairments is projected to increase quickly because of demographic changes,[1] and the use of digital technology will be a key factor in their well-being.

Software accessibility features and multimodal input methods mitigate some of these difficulties.[2] The range of accessibility features commonly available rely on software processing of computer input such as: altering the repeat-rate of a keypress; supporting alternative input modalities such as speech or eye-gaze-tracking; and making on-screen buttons larger. In addition, physical assistive technology (AT) devices, such as keyboards and mice with nonstandard physical attributes, are available. However, in light of the large and growing population of people with motor impairments, there is still scope for research and innovation to improve the lives of people with disabilities.[3]

We know that many people with disabilities develop custom and sometimes ad hoc solutions to make common tasks easier for them.[4,5,6] We also know that a co-design process that involves one or more collaborators from different backgrounds is a powerful way to create these custom approaches.[7,8] In recent years, we have seen the adoption of the latest physical prototyping techniques, such as 3D printing and laser cutting, during the co-design of ATs.[5,6] Our research goal is to explore the potential of

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modern "physical computing" electronic device prototyping tools and techniques[9] to complement and build on these established approaches by enabling the creation of custom digital AT input devices for smartphone and computer use at work and at home.

In this article, we present a multiphase study comprising a survey and in-depth interviews focusing on the pain points that people with mild-to-moderate upper limb motor impairments have when interacting with their computers and smartphones, and adaptations they adopt to improve things. We also ran a series of workshop sessions with three of our interviewees and a number of expert designers without disabilities, co-designing prototypes that ultimately validated many of the insights discovered during our data collection.

BACKGROUND

Due to economies of scale, established computer interaction paradigms target the mass market and largely do not prioritize the needs of people who live with a disability.[10] There have been many advances through the years in optimizing device input, but there are still issues to overcome. As a result, many people with motor impairments find their productivity limited simply because of the challenge of using common human interface devices (HIDs), which often require more manual dexterity than they have.

The performance of input devices has been extensively studied, for example, comparing touchscreen and mouse input for people with motor impairments,[11] and the implications this has when interacting with personal devices.[12] Anthony et al.[13] developed a rich characterization of touchscreen usage, unveiling that while many people with motor impairments find these devices empowering, accessibility issues still exist. For example, Findlater et al. showed that participants with motor impairments have a three-fold increase in pointing errors when using touchscreens, compared to users without such impairments.[11]

According to the report that Li et al.,[14] multimodal interaction can support user independence, addressing accessibility needs. They found that integrating multiple input modalities can be useful because it offers input redundancy and variability, leading to improved reliability, efficiency, and privacy. Multimodal input can also boost self-assurance in social interactions by mitigating the risk of false activation.[14] We have also seen many implementations of these ideas, some at the research level, such as EdgeWriter,[15] and others deployed in consumer devices that use accessibility features to enable multimodal voice or eye-gaze input controls. Multimodal inputs clearly offer opportunities for individuals with upper-extremity mobility limitations, helping them adapt to the complexity of different contexts.

Wentzel et al.[2] analyzed the ecology of devices people with limited mobility often use to overcome accessibility barriers. In their report, cognitive load is a prominent consideration when designing these multimodal solutions. Although the most common combination is using a keyboard and mouse simultaneously, evidence shows that almost half of users use more than two devices. Through a rich diversity of configurations, Wentzel et al. found that users with mobility impairments use multimodality as a common remedy for accessibility issues, either adapting their usage style to the device, or their device to the application.

Nevertheless, the obstacles to accessible use of input devices persist. Bowman et al.[12] examined the challenges associated with the low adoption and high abandonment rates of accessibility features among individuals with mild-to-moderate dexterity impairments. They identify several barriers contributing including physical obstacles, such as hard-to-operate buttons, technical issues like complicated software configurations, and challenges with learnability and usability.

Kane et al.[16] investigated the ad hoc and custom strategies people with motor impairments use to cope with inaccessible devices, which they do despite all the available accessibility features. Bowman et al. found large gaps where accessibility features are available but users are unlikely to seek them out, instead relying on self-created workarounds and adaptations to improve usability.[12]

Not surprisingly, there is growing interest in overcoming these challenges to increase accessibility. Technical solutions include various devices and accessibility features that can work with or are built into mainstream products and services, although these frequently have limitations.[17] Rethinking the established mainstrem computer and smartphone input modalities provides an opportunity to decrease the digital divide, growing opportunities for people with disabilities to build friendships, engage socially, and gain access to education.[18]

Researchers have shown the importance of prototyping tools in enabling accessibility solutions.,[5,19,20] Hofmann et al. have shown the potential for 3D printing technology to be used by clinicians as part of the occupational therapy process, to adapt and design AT devices.[19] Close participation in the co-creation process can also lead to better adoption rates of ATs.[6,7] Our work builds on this by combining a co-design approach[8] with a particular modern rapid electronics prototyping tool[9] to explore challenges faced when using computers and smartphones and new solutions that may now be possible.[21]

DATA COLLECTION

We recruited participants for our research with the help of the China Disabled Persons' Federation. Participants were compensated for their time.

Phase 1: Discovery Survey: We asked people who self-reported as having motor impairments questions about their relationship with AT. Inclusion criteria included living in China and regularly using at least one computer or smartphone. We received 41 responses (n = 41, subsequently referred to as "Sx, where x" refers to a specific respondent). Ages ranged between 18 and 60 years (M = 30.5, SD = 5.02), with 46% identifying as female and 54% as male. Two individuals lived alone, the rest lived with their families. Participants' educational and economic backgrounds can be found in Tables 1, 2, and 3 in the Appendixes.

We asked participants about their use of computers and mobile devices, the accessibility features they used, their use of AT in general and of HIDs in particular. Several questions included free-form text fields to capture specific obstacles and solutions. The questionnaire is reproduced in the Appendixes.

Phase 2: Semistructured Interviews: We then used in-depth semistructured interviews to collect more data relating to computer and smartphone usage in the context of home and work life. We identified Phase 1 participants suitable for participation in Phase 2 through purposive sampling, including only people with motor impairments who use AT.[22] We also looked for participants who had engaged strongly by providing details in the open-ended Phase 1 questions. We selected and recruited nine participants (n = 9), hereafter relabelled as "Px," with ages ranging between 18 and 60 years (M = 32.4, SD = 5.83); 56% identified as female and 44% as male. More detailed demographic information is available in the Tables 4 and 5 in the Appendixes.

All participants had some form of physical limitation that affected their upper limb movements: P1, P8, and P9 are living with Cerebral Palsy; P3 with Hypoxia's sequelae; P4 has muscle atrophy by Charcot-Marie-Tooth disorder; P2, P6, and P7 have with different spinal cord injuries; and P5 has oligodactyly.

We conducted the interviews at the participants' homes, allowing for a more naturalistic environment and context-specific observations. We used information from our discovery surveys to more quickly pinpoint topics relating to obstacles our participants faced when using HIDs for their computers and smartphones. During the interviews, the participants were encouraged to use their own computers and mobile devices to demonstrate their daily routines as accurately as possible. We recorded short video clips and took photos of the participants' technology usage for subsequent deeper analysis together with their answers.

Participant P2 employed distinct muscle groups for mouse manipulation, emphasizing the meticulousness required due to the time-consuming nature of rectifying minor errors, especially when editing text placement. P3 demonstrated proficient computer usage but encountered delays when transitioning between keyboard and mouse input. Due to limited finger dexterity, P4 relied on knuckles for touchscreen and keyboard usage.

Due to spinal cord injuries, P5 resorted to left thumb keyboard input, while P7 predominantly typed using the joint of their little finger with both hands. P6 shifted to exclusively using a smartphone over a computer due to the ease of typing on a touchscreen. P8 exhibited fluent movement in their right hand but struggled with accidental key presses due to insufficient finger strength in the left hand. Participants P1 and P9 found keyboard shortcuts challenging due to limited hand mobility.

Figure 1 shows some of the computer- and smartphone-based interaction techniques used by our participants.

All conversations were in Mandarin Chinese, led by one of the coauthors. Transcripts were translated into English and coded independently by two coauthors alongside the relevant photos and videos, and emerging themes were identified as per Braun and Clarke.[23] The resulting themes were reviewed and merged through discussion before a final consolidation round involving all the authors.

EMERGENT THEMES

Following our analysis of the interview transcripts, we identified three significant themes.

Accessible inputs do not meet expectations: We learned how the growing number of software-based accessibility features in modern computer and smartphone operating systems often still fall short of needs. Participants explained that the promise of multimodal input rarely met their expectations. Speech-, gesture- and eye-gaze-based modalities are all supported in some form on computers and phones, and many participants had tried using them. S12 told us *"I wish they'd improve the voice input recognition rate."* P9 said *"I tried to use a computer input method with*

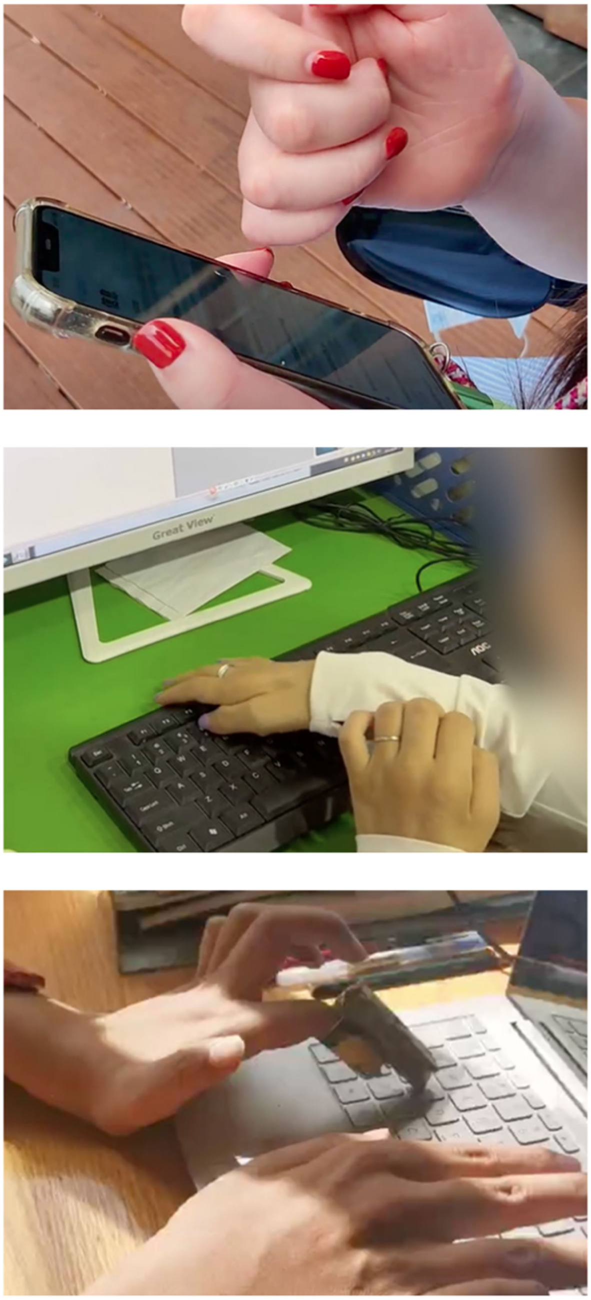

FIGURE 1. Photographs taken during our observations. Top: P4 uses their right-hand knuckles to operate a smartphone; due to limited finger dexterity, their left hand can only hold objects. Center: P5 primarily uses their right thumb to press keyboard keys since their other fingers lack sufficient strength, and sometimes they use their left hand to help with movement and to press the keys consistently. Bottom: P8 wears a custom accessory on the index finger of their left hand to improve typing speed and accuracy by pressing the desired key without their other fingers touching the keyboard.

speech-to-text recognition… but it was inaccurate." and S27 had *"hoped that by now we would have full-process voice control, including wheelchairs, nursing beds, and others. But even answering a call with voice control is not convenient."*

A majority of the participants focused on their slow typing speed. P9 told us *"The only way to improve typing speed is to practice…"* Participants perceived productivity as closely related to typing speed and that *"computer shortcuts are very difficult to use."* Wanting to increase typing speed was almost a consequence of frustrations with the current status of inaccuracies from speech-, gesture-, and eye-gaze-based modalities. The time required to correct errors therefore overshadowed the potential benefits of these accessibility features.

Finally, P2 mentioned she would like to have another way to adjust the size of a picture, imagining that if *"it could move with my eyes or my head, that would be dope."*

Complexity often intimidates: We found that most people with motor impairments knew about software features which could, in theory, be enabled to their benefit—but still did not use them. For example, participant S5 reported that, when using the smartphone, *"I wish I could use some of the accessibility features. They always have words I can't understand."* Some participants expressed concern about their complexity. For example, S13 reported *"In terms of system, some things I don't dare to touch. I don't dare upgrade or change because I have to be careful about making mistakes. I know nothing about the system. I have not used many accessibility features, but I don't dare to try."* We imagine that both participants could have benefitted from the accessibility feature StickyKeys, but they did not think it was useful for them.

P4 reported a need to press two buttons simultaneously to take a screenshot on their phone. Although they knew there was an accessibility feature based on head gestures, they instead chose to continue asking for assistance with operating the phone's buttons. When asked why, they replied, *"I was happy at first. I felt it was so cool, and I was so independent. But it didn't work well. It would start taking screenshots non-stop when I was talking on the phone. It drove me crazy. I couldn't control it, and then I had to delete unnecessary screenshots one by one."*

Transparency keeps it simple: Both survey participants and interviewees reported difficulty using standard input methods like touchscreens or their laptops' joysticks and trackpads. The most common approach to overcoming this was simply to use an additional external keyboard, mouse pointer, or trackball. For example, P1 said *"When typing, the palm is easy to* *touch the touchpad, which affects the positioning of the cursor."* This experience is aligned with P2, P8, and P9 being unable to set a suitable spacing or adequate sensitivity. P2 used a separate wired mouse to control the pointer, and deactivated the touchpad.

Across all these examples, participants clearly valued feeling "in control." They did not use hidden settings or complex modalities, but tended instead to use devices and techniques that were easy to understand and adapt. These transparent setups were intuitive to create, relatively easy to debug and simple to use.

CO-DESIGN WORKSHOP

To expand on the insights gained during our data collection and to explore new solutions built using modern "physical computing" device prototyping tools, we organized a co-design workshop. Three of our participants with diverse upper limb motor impairments worked with groups of designers without disabilities. The workshop consisted of three 2 h sessions held on consecutive weeks, with each session guided by three facilitators.

The co-designers were recruited from the design studio of an international design company. Co-designers' ages spanned from 23 to 35, with the majority being Chinese nationals (79%) and a slightly higher representation of females (58%). They also represented different stages of their careers. They brought a wide array of skills, including expertise in electronics, software engineering, user experience, graphic design, and industrial design. The number of participating co-designers varied—28 in the first session, 22 in the second, and 27 in the last.

The participants with motor impairments in the workshop sessions were:

- *P2:* An individual living with hemiplegia from a spinal cord injury, who operates computers single-handedly by alternating between the mouse and keyboard.
- *P5:* A person with oligodactyly, having a total of five fingers, including thumbs on both hands, who struggles when pressing key combinations and maneuvering within the narrow spaces between keys.
- *P9:* A college student with cerebral palsy, which affects her typing accuracy and control of the mouse.

Session 1—Introduction and direction setting: We introduced the attendees to the emerging themes obtained from previous surveys and interviews. Participants P2, P5, and P9 were encouraged to brainstorm ideas and apply the themes to enhance their own technology accessibility. We instructed participants and designers to form smaller groups, each comprising one facilitator, one participant, and several co-designers without disabilities. Each team presented their notes, allowing for constructive feedback and discussion.

The facilitators also spent around 30 min introducing the physical computing tools we had selected for the workshop: Jacdac,[9] micro:bit,[24] and Makecode.[25] Together, these make up a flexible physical computing and electronic device prototyping platform that simplifies digital device creation, including USB and Bluetooth input devices that can complement or replace traditional mice and keyboards.

Session 2—Lo-Fi Prototyping: We ran a curated series of experiences to trigger interesting conversations among designers and participants. While the simulation of disabilities has been pointed out as an inadequate approach to generate empathy,[26] our participants with motor impairments wanted to let the co-designers share their experiences with accessibility challenges. Each participant devised an activity for the co-designers, offering their personal perspectives about their accessibility needs and the rationale behind the activity they chose to share. Using an affinity mapping framework, participants and designers worked with sticky notes as a means of brainstorming ideas. The groups collaborated to develop low-fidelity paper prototypes to crystallize and further refine their ideas.

Session 3—Validation: We comprehensively reviewed the needs that were identified and shared during Session 1, and the low-fidelity prototypes generated during Session 2. The ideas were critically analyzed and discussed as a group. Each participant with a motor impairment collaborated with a team comprising one of the facilitators and a subset of the designers to create a series of more refined iterations. At the end of the session, the final prototypes were presented back to the entire group, and feedback was actively solicited.

After each team had developed a sample prototype, we conducted a collective sharing session in which these prototypes were presented to everyone. Participants and designers actively provided feedback on the usability and functionality of these prototypes.

PROTOTYPES CREATED

We were pleased with the ease with which the participants with motor impairments worked with their co-designers to build new input devices. The simplicity and intuitiveness of manipulating the Jacdac modules allowed the groups to quickly iterate solutions, despite

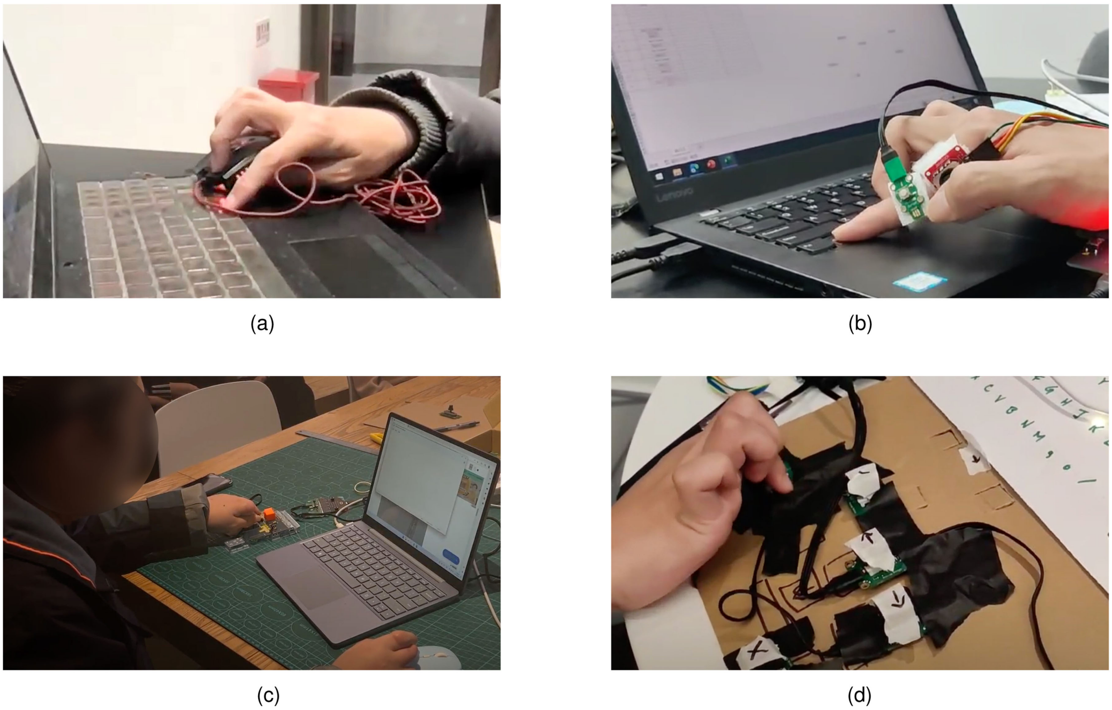

FIGURE 2. (a) P2 holding their mouse on top of the keyboard to press keys while moving the cursor. (b) Mouse-ring prototype being tested by P2. (c) P5 is testing the external keypad prototype in an early wired version. (d) P9 operating the joystick-driven keyboard prototype.

the workshop sessions being limited to just 2 h. As a result, three fully working solutions were developed, one for each motor impairment. These three mini-case studies are described here.

Finger Mouse

P2 knew about accessibility features, but preferred to reposition his mouse over the laptop keyboard, as seen in Figure 2. This has obvious limitations, for example, the difficulty of pressing key combinations on the keyboard while simultaneously clicking and dragging.

The group reflected on the strengths and limitations of existing software-based accessibility features, and P2 shared his reluctance to change the accessibility features on his computer as suggested by some of the designers: *"Once I had to take my computer to the IT service because of something I changed in there, I prefer not to mess with those settings."* P2's motivations and several possible solutions were discussed in depth by the group who initially explored a head-mouse function, which later transformed into a ring with a series of buttons designed to control the pointer direction.

Ultimately, the group settled on a mouse ring to control the pointer with one hand and simultaneously type. This is designed to be worn comfortably on one finger, allowing users to move the cursor on their computer or remotely operate their phone. P2 mentioned that he could imagine many more situations for using it, commenting that *"… another scenario is playing games, in many types of game operations, it's a combination of mouse and keyboard; these are very important for me."* Several co-designers confirmed they would be interested in using such a device to complement their current pointing devices when using specialized modeling software.

Wireless Autoconfiguring Macropad

P5 shared her frustration at being slow both when typing and when using graphic design software, because of being limb different. In particular, she explained how the key combinations she could use were limited to one or two keys. However, adding external keys was not something she had considered. On this basis, the group working with P5 created a wireless "macro" keypad with contextually configured dedicated key shortcuts. The prototype could be wirelessly connected to both computers and smartphones, complementing existing input methods and offering a highly adaptable means of interaction.

The group chose to make the device wireless because they anticipated the need to make its position fully customizable, empowering P5 to tailor it to her precise requirements. Another relevant feature was its contextual intelligence; the system adapts to the user's current context or task. For example, if the user is engaged in word processing, the keypad would intelligently recognize this context and map the external buttons accordingly. If the user later switches to web browsing, the keypad seamlessly adjusts its shortcuts to align with the new context. This dynamic mapping ensures that the assigned functions are always relevant and efficient for the user's ongoing activities.

P5 appreciated the device's familiar form factor, remarking *"it is like using my mobile phone."* Reflecting on the ability to create custom hardware, she commented *"I think the prototype was good in itself, but what I found more relevant is realizing I can increase the keyboard space and change the keyboard to make it more flexible. This is the invention I want."*

Joystick-Based Keyboard

The input scenario that P9 and her co-designers concentrated on was reducing her typing error rate coupled with the corresponding time taken to correct mistakes, which had been frustrating her.

After the workshop sessions were complete, P9 reported that *"The first time we tried, pressing buttons [of a Jacdac prototype] was too difficult. The second exercise we did [using a small display and an automatic sequence of characters] was too long to wait."* So P9 showed her co-designers how her joystick-based wheelchair controller worked. Observing how confidently she used this, the group decided to integrate that familiar modality into their design of a new computer and smartphone input device. They co-designed a virtual keyboard, where the joystick lets the user navigate a visually displayed keyboard layout on a spacious LED panel. This design choice significantly reduces the physical effort required for typing, as users can move the joystick to select the desired key, eliminating the need to physically press keys on a traditional keyboard. With this benefit, the error rate of the current keyboard can be reduced. P9 remarked: *"I prefer this new way, like my wheelchair control. Now I can know where the letter is, and I can select the letter by myself."*

The three iterations reinforced the value of the co-design process and the power and flexibility of a modern electronic device prototyping experience, like that provided by Jacdac and MakeCode.

Reflecting on the process of the co-design workshops, P9 shared: *"Designers became very interested in the electric wheelchair I was driving. Some also tried to drive it. They observed how I skillfully drove the wheelchair and drew inspiration from the process."*

DISCUSSION

In this work, we have explored the obstacles people with motor impairments face when using computers and smartphones. Our initial data collection stage builds on the literature relating to people with mild-to-moderate mobility impairments interacting with standard input methods. We identified three emergent themes that were later used to motivate the collaborative cocreation of new solutions. Here, we reflect on the co-design process and the three case studies which emerged.

Familiarity

"The Background" section explains that friction related to learnability and cognitive load strongly influence the success of solutions that help people with motor impairments to overcome their difficulties.[2] Working with our participants, we observed that familiarity was a valuable characteristic. There was a clear reluctance to use unfamiliar accessibility features, and as we reported above *"complexity often intimidates."*

Reflecting on our three case studies, P9 chose to build a joystick-based keyboard which resembled the wheelchair controller that she was already familiar with. Similarly, the wearable mouse-ring that P2 co-designed, and the contextual programmable keypad envisioned by P5, were both built from well-known elements. In each case, the input experience was new, but there was enough familiarity to make it intuitive and stress free.

Transparency

Reflecting on our discovery survey, interviews and the co-design workshop sessions, we observe that time-and-again USB and Bluetooth HID hardware is popular with people with motor impairments. This was particularly apparent through the emergent theme highlighting that *"transparency keeps it simple,"* which revealed how software accessibility features were often shunned in favor of an additional external HID connected over USB or Bluetooth. HIDs are easy to understand, intuitive to use, and above all transparent in operation. It is clear how they work and what to do if they do not.

In our workshop sessions, we leveraged this insight and guided participants to co-design new USB and Bluetooth HID hardware. This appears to have been a successful approach, as each of our case studies resulted in a solution that the participants with mobility impairments were happy with. We have not seen this specifically called-out in prior literature, but we think it could be an important factor in the success of new input methods for people with mobility impairments, whether used standalone or in a multimodal fashion.

Ownership

Initially, our participants were reluctant to adopt unfamiliar technology, because of bad experiences previously. However, during the co-design workshops, as they iterated on different prototypes with their co-designers, we saw this attitude change quite quickly. We observed their sense of agency in the design process growing and they became more adventurous as their groups moved from drawings to paper and then to real functional models. Ultimately, we sensed a level of pride in the creation process and the resulting solution.

The prototypes developed obviously had many shortcomings. For example, the wearable technology that P2 used in his design was not close to the level of integration of consumer electronics, and the macropad of P5 did not support all applications. Nevertheless, the three participants strongly advocated for their solutions. This is consistent with prior work that reports how DIY approaches lead to high AT adoption rates.[7]

The Value of Physical Computing

The physical computing tools we chose—Jacdac, the micro:bit, and MakeCode—are designed primarily for school education. However, the quick, easy, and intuitive experience they provide in the classroom context was equally valuable in our use-case; our participants quickly became competent with Jacdac's plug-and-play hardware and MakeCode's block-based graphical coding. This enabled them to rapidly prototype working and useful electronic devices, in an analogous way to previously reported purely mechanical protoyping.[5]

During Sessions 2 and 3 we were particularly pleased to note that all team members, including the participants with motor impairments, were engaged with both the physical device creation and with the coding. The block-based code was not only easy to create, but perhaps more importantly in a co-design scenario like ours, it was easy for everyone in the team to follow. At one point, P5 took over from the designer who was working with MakeCode to illustrate a particular idea she had. A further benefit of the ease with which participants worked with the physical computing technologies was the confidence it gave them. We heard observations like *"I've only seen this in movies"* and incredulous comments like *"Did I just make this?"* This clearly spurred creativity, although occasionally we had to manage expectations regarding the capabilities of the technology.

Jacdac modules like buttons and joysticks are indeed larger than their underlying electronic components, which introduces constraints on how closely the components can be arranged. But this disadvantage seemed to be outweighed by Jacdac's accessible nature compared to more intricate and delicate solutions, as noted previously.[21]

CONCLUSIONS AND FUTURE WORK

In conclusion, our study has shed light on the difficulties people with motor impairments encounter when using existing solutions for interacting with computers and smartphones. Leveraging surveys and interviews, we identified themes that we later used to inform a co-design workshop. Many participants reported initially wanting to use voice, gesture, or eye gaze-based input methods to enhance their interaction with digital devices. However, even widely available accessibility features often do not meet expectations, resulting in mistakes that have to be corrected and dissatisfaction. We also observed that they do not work in a transparent way and can be so complex to configure that they are intimidating for many users. As a result, our participants often shied away from using them despite their potential for more effective input.

Our workshop sessions resulted in three case studies of new input devices built with modern physical computing tools: a finger mouse, a wireless autoconfiguring macropad, and a joystick-based keyboard. Reflecting on these in conjunction with our survey and interview data, we observed that successful AT input solutions are typically *familiar* to their users and *transparent* in operation. Creating them through a co-design process resulted in a sense of *ownership* and pride which goes a long way toward successful adoption.

In the future, we would like to explore co-design of custom input devices that can be used for longer periods of time. This likely needs more refined designs that combine the physical computing capabilities we explored in this article with the mechanical prototyping techniques reported in the literature. This could allow more compact and integrated hardware with enclosed circuit boards, which could provide reliable operation over months and perhaps even years. This would ultimately allow us to develop and understand a broader landscape of technologies and solutions supporting computer and smartphone users' accessibility needs. An interesting additional research direction would be exploring the adoption mechanisms of ATs, potentially through a comparative study, which includes design, development, and configuration.

We would also like to address some of the limitations of our study, in particular, to complement what we learned in China with input from other geographies, including additional low- and middle-income countries from the global south. We also know that our participants, who all owned a smartphone and nearly all owned a computer, do not provide a representative cross section of people with motor impairments.

We hope that by sharing our processes, experiences, and observations, other researchers and practitioners will be empowered and inspired to leverage physical computing tools to build and evaluate input devices for people with motor impairments as they use computers and smartphones at home and at work.

APPENDIX A SURVEY PARTICIPANT DEMOGRAPHIC INFORMATION

TABLE 1. Educational information from survey respondents.

Education information		Qty	Frequency
Type	Public School	19	46%
	Special Education	11	27%
	Private School	2	4.9%
	Never formally attended	4	10%
	Homeschooling	2	4.9%
	Online Education	3	7.3%
Highest level	Master's Degree	3	7.3%
	Bachelor's Degree	12	29%
	Senior High School	5	12%
	Junior High School	5	12%
	Primary School	5	12%
	Other	11	27%

TABLE 2. Economic information from survey respondents.

Economic information		Qty	Frequency
City Tier	Tier 1	19	46%
	Tier 2	9	22%
	Tier 3	8	20%
	Other	5	12%
Occupation	Unemployed	20	49%
	Employee	8	20%
	Self-employed	7	16%
	Student	6	15%
Income	Min wage or less	21	51%
	Min to average wage	2	4.9%
	Ave wage or more	4	9.7%
	n/a	14	34%

TABLE 3. Devices owned by survey respondents. note that although 41% of our survey respondents reported tablet ownership, in this article, we focus on their use of smartphones and computers, both of which were significantly more prevalent.

Device information		Qty	Frequency
Type	Phone	41	100%
	Computer	32	78%
	Tablet	17	41%
Mobile OS	Android	25	61%
	Apple iOS	3	7.3%
	Other	3	7.3%
Computer OS	MS Windows	28	68%
	Apple MacOS	3	7%
	Other	2	4.9%

APPENDIX B ONLINE DISCOVERY SURVEY QUESTIONS

1) What is your age?
2) What is your gender?
3) What is your nationality?
4) What country and city are you in now?
5) What is your current highest education?
6) What is your educational background?
7) Please explain the details of your educational background.

8) Where did you receive your education? (multiple choice)
9) What is your occupation?
10) What is your personal monthly income? (multiple choice)
11) What is your education/work goal, the academic qualification/job position you want to achieve?
12) What is your physical condition? (multiple choice)
13) Please explain in detail your physical condition.
14) In what way does the above situation trouble you in your daily life?
15) Who do you live with? (career/family/etc.)
16) Have you tried using technology to help yourself reduce the inconvenience in your life?
17) Please list all the technologies or products you have tried.
18) Are you still using the technologies or products you listed?
19) Which technologies or products do you use more frequently?
20) In the process of using these technologies or products, what shortcomings or shortcomings did you find?
21) Please explain the reasoning behind your answer.
22) Describe ways you learn or collect information about new AT.
23) To learn about AT, what is your information channel/source? (multiple choice)
24) For what reasons do you choose that channel of information?
25) What electronic devices are you currently using? (multiple choice)
26) What is your mobile phone operating system?
27) What is your computer operating system?
28) What is your tablet operating system?
29) Please add details to the previous answers.
30) Do you know the accessibility features of these electronic products?
31) What are the accessibility features you are using?
32) Which accessibility features are more helpful to you?
33) What would you say is the reason why you do not know the accessibility features of your electronic devices?
34) Please list the biggest challenge you encountered in the process of using electronic devices. (1 to 3)
35) What accessibility features do you think you would enjoy so that your experience is smoother? (1 to 3)
36) What external input devices are you using?
37) Are they sufficient to meet your needs?
38) Can you expand on how they might be improved to serve you better?
39) Please explain the reasons why.

APPENDIX C INTERVIEW PARTICIPANT DEMOGRAPHIC INFORMATION

TABLE 4. Educational information from interview participants.

Education information		Qty	Frequency
Type of education	Public School	7	78%
	Special Education	1	11%
	Homeschooling	1	11%
Highest level obtained	Bachelor's Degree	5	56%
	Senior High School	3	33%
	Primary School	1	11%

TABLE 5. Economic information from interview participants.

Economic information		Qty	Frequency
Occupation	Unemployed	1	11%
	Employee	4	44%
	Self-employed	3	33%
	Student	1	11%
Income	Min wage or less	3	33%
	Min to average wage	4	45%
	Ave wage or more	2	22%

APPENDIX D SEMISTRUCTURED INTERVIEW QUESTIONS

1) What cursor positioning hardware—mouse, touchpad, trajectory ball, or others—do you use?
2) Why do you choose this hardware?
3) How did you learn about this particular hardware?
4) Please describe a situation where your cursor positioning encountered difficulties.
5) How do you overcome this difficulty?
6) What help or assistance would you want to get when the cursor is positioned?
7) Can you describe the keyboard you use?
8) Why do you choose this keyboard?
9) How do you enter special/punctuation symbols (such as Â¥?@)?
10) How do you use Excel?

11) How do you locate the cell, line, and column?
12) How do you type characters with Pinyin input?
13) What input method do you use?
14) What difficulties do you encounter when you type characters using Pinyin input?
15) What help/assistance do you want to get when typing?

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