ProCom: Designing and Evaluating a Mobile and Wearable System to Support Proximity Awareness for People with Autism

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ABSTRACT
People with autism are at risk for social isolation due to differences in their perception and engagement with the social world. In this work, we aim to address one specific concern related to socialization—the understanding, awareness, and use of interpersonal space. Over the course of a year, we iteratively designed and tested a series of concepts for supporting children with autism in perceiving, understanding, and responding to physical proximity with other people. During this process, we developed ProCom, a prototype system for measuring proximity without requiring instrumentation of the environment or another person. We used a variety of low and high fidelity prototypes, culminating in ProCom, to assess the feasibility, utility, and challenges of this approach. The results of these iterative design engagements indicate that wearable assistive technologies can support people in developing awareness of physical proximity in social settings. However, challenges related to both personal and collective use remain.

Author Keywords
Autism, social skills, self-monitoring, proximity, wearable computing, children, parallel design

ACM Classification Keywords
K.4.2 [Computers and Society]: Social Issues- Assistive technologies for persons with disabilities

INTRODUCTION
People with autism often struggle with normative communication and socialization patterns [16,39]. These challenges in turn can lead to social isolation. However, people with autism are not anti-social, far from it. In fact, children with autism often report a desire for more peer social interaction, while experiencing poor social support and more loneliness than their typically developing peers [3]. Despite interest in socialization, children and adolescents with autism are at increased risk for peer rejection and social isolation when they are integrated into mainstream classrooms [8]. Finally, social skill difficulties may precede mood and anxiety problems later in life [17].

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Although recent HCI research has focused on supporting socialization for people with autism in face-to-face contexts, these have largely focused on learning how to process emotions of the face (e.g., [1,32]). A wider variety of nonverbal social behaviors, however, are important to socialization, such as head nodding, making eye contact, gesturing, monitoring proximity, and touch [22]. These social behaviors tend to be underrepresented in the intervention literature, perhaps because they can be more difficult to quantify and are less well-understood neuro-biologically. In our work, we tackle one of these issues, proximity regulation, which is the ability to sense and respond to the physical distance between individuals [16,27,28]. Proximity regulation is critical for successful social interaction, as its disregulation can lead to personal space violations (and ensuing feelings of discomfort), as well as the inadvertent miscommunication of social intentions (e.g., aggression, defensiveness, social interest or disinterest, etc.) [20,21].

Estimating the appropriate proximity to stand from someone is a complex and dynamic social judgment [20,27,28,36]. This skill depends on many factors, such as age, gender, emotions, culture, and the relationship between the people in the interaction. Despite the complex reasoning required, most people naturally learn where to stand during social interactions [20,21,29,35,36] by the age of five [31]. However, for people with autism, this may not be automatic [27,39], leading them to act in ways that are unexpected by others [15]. These unexpected behaviors can make people feel uncomfortable, and result in limited opportunities to make and maintain relationships [18].

Certainly, one set of solutions to these challenges lies in making neurotypical people more aware of and sensitive to the challenges people with autism experience related to social proximity. This approach would potentially reduce the discomfort felt by non-normative behaviors and should be explored in the interest of considerations for a neurodiverse world. In the short term, however, therapists, parents, and people with autism themselves have expressed concern about limitations in opportunities brought on by differential experiences with proximity. Thus, child development specialists have explored, with moderate success, teaching expected social distances through self-awareness training, which progresses through self-monitoring, self-regulation, and self-evaluation [4]. Standing too close or too far away, and turning one's body away from the speaker have been targets of therapy [6].

Current best practices in educational settings tend to use video modeling lessons in virtual scenes [10]. While these technologies can deliver essential guidance, they still cannot offer timely assistance *in situ*. Whereas video lessons and existing assistive applications are limited and fixed, real life has endless contexts and changes dynamically. Consequently, technology that provides real-time context awareness, such as proximity during social interaction, could help people with autism use proximity more successfully. In this work, we were interested in understanding how assistive technologies might augment face-to-face interactions, particularly related to proximity.

To address these questions, we conducted a series of iterative design explorations over the course of a year. We initially explored a variety of concepts and potential designs related to sensing and visualizing interpersonal space with both adult designers and children. We then iterated on these concepts, validating our designs with a cooperative design team member with autism. We then designed and developed ProCom, a single-user prototype system that combines wearable sensors with a mobile application. We used ProCom as a technological probe to evaluate how such a design might function in practice to help people with autism develop awareness of their real-time proximity. In particular, a key concept that emerged in our work and was tested with ProCom was the potential to do this kind of sensing while only instrumenting the user, not the environment or other social actors. We tested this approach and probed for further design insight through a laboratory study with children with autism combined with interviews with them and their parents.

This work contributes to the nascent but growing field of mobile and wearable assistive technology related to behavioral health. Specifically, we present analysis of visual metaphors appropriate for understanding and describing relative location and proximity sensing for a population that can struggle with these concepts and demonstrate how these metaphors might reasonably translate into usable designs. Additionally, we demonstrate how a combination wearable and mobile system for sensing and visualizing proximity information can be understood and acted upon by children with autism. HCI researchers—as well as therapists, clinicians, and people with autism—can build on this work to enable new kinds of measurements, interventions, and assistance for real-time face-to-face interactions in a self-contained mobile system.

BACKGROUND AND RELATED WORK

To understand the potential for novel technological interventions to support people with autism, we provide background on the concept of proximity in socialization. We then follow with a summary of the role proximity has played in technological systems to date, ways technologists have measured proximity, and HCI research focused on supporting face-to-face social interactions. Taken together, this related literature indicates that social proximity sensing is an interesting and challenging problem for the behavioral health informatics space that, when leveraged properly, has the potential to support people with autism to have more successful social interactions through self-regulation.

Proximity

Proximity is a basic spatial requirement of humans to mediate behavior, communication, and social interaction [39]. In general, proximity includes two concepts: personal proximity and social proximity. Personal proximity, often referenced as personal space, travels with each individual everywhere they go and may expand or contract depending on context. There are well established metrics regarding proximity, or "personal interaction bubbles," in which space is divided into four parts: intimate space, personal space, social space, and public space (see Figure 1) [19]. Most people value their personal space and feel discomfort, anger, or anxiety when others encroach on it [21].

In this model, intimate space is for embracing, touching or whispering; personal space is for interactions among good friends or family; social space is for interactions among acquaintances; and public distance is used for awareness of

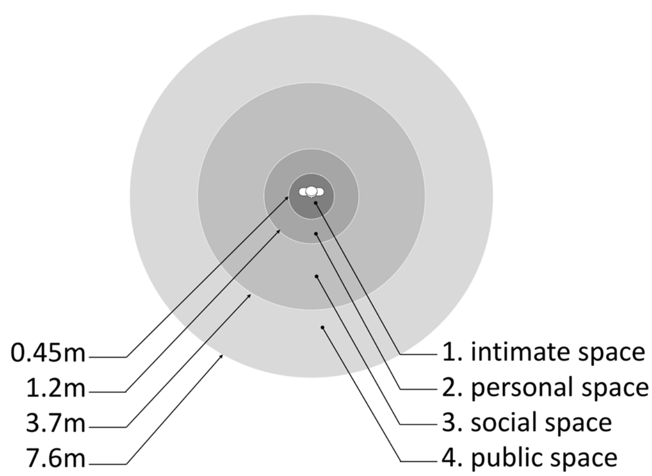

Figure 1: Interpersonal spaces showing radius in meters, including four parts: intimate space, personal space, social space, and public space.

one's surroundings. This concept has been adapted to teach social proximity to people with developmental disabilities [6,44].

Technology for proximity measurement

A variety of methods have been used to measure proximity, all of which are successful for a variety of applications but limited for social proximity usage. Indoor localization methods use radio waves, magnetic fields, acoustic signals, or other sensory information collected by mobile devices [46]. Outdoor-positioning, a much simpler proposition, typically uses GPS to measure each individual's position and then calculate proximity via position sharing. With the development of mobile phones, location-based methods can be easily deployed in wearable applications, but they can often only be used in calibrated environments. Additionally, these methods only perform well for large-scale localization when meter-level accuracy is sufficient.

Computer vision has been used in prior projects related to people with autism. For example, distance-based features measured by camera have been used to automatically detect and classify positive and negative robot interactions with children with autism [13,14]. There are two challenges with this approach, however. First, given what we know about people with autism experiencing proximity differently than their typically developing peers, this judgment may not accurately depict the quality of the interpersonal interaction. Second, a vision-based approach like this requires instrumenting the experimental space with an overhead camera to detect the positions of the participants and other objects in the room. This kind of heavy surveillance is expensive, difficult to install, and may cause discomfort or behavior change in the participants.

Other solutions provide mobile devices with an awareness of the presences of other devices with less instrumentation requirements than full overhead computer vision systems [2]. For example, Dearman, *et al.* determined the relative orientation of proximate devices using the backside camera [9]. This approach uses the camera to automatically take a picture of the ground while the user engages with the phone. By stitching together two pictures using features common in both images, the relative orientation can be determined. This approach requires no additional equipment but only works for orientation measurement when two people, with two devices, stand within 1.5 meters of each other. Several commercial products (e.g., Google's Project Tango or the Microsoft Kinect) use computer vision to give devices the ability to understand their position relative to the environment around them. Tango is designed to work best indoors at moderate distances between 0.5 to 4 meters, which cannot cover the intimate space desired in this work. Kinect cannot be applied in mobile applications.

Finally, portable sensors offer some hope for proximity measurement in behavioral health informatics systems. For example, Gessaroli *et al.* used a digital laser range finder to measure the distance between the confederate's toes and the participant's toes in research of personal space regulation in childhood autism [18]. This approach provides valuable clinically relevant data but would not be appropriate for an intervention given its placement of a laser site on the target. An alternative is acoustic ranging sensors [34], including ultrasound and audible acoustic, that are used for centimeter-level accurate proximity detection. When in use, the sensors emit a sound impulse and measure the elapsed time of the returned echo signal reflected off a detected object. However, they do not work well in measuring distance to a person due to the inherent sound absorption of clothing.

Technology for social interaction for autism

Recently, there have been considerable advances in the research on innovative technology for social interaction of people with autism [5]. Virtual Environments (VE) have been shown to be useful for social interventions for people with autism. Specifically, using VE, interventionists can mimic specific social situations in which the user can participate in role-playing. For example, proximity zones have been differentiated in virtual space as participants were observed to maintain different distances when approached by differing virtual objects: people and cylinders [23]. Likewise, youth with autism vary distance from others in virtual space to practice one's virtual presence, virtual co-presence, and virtual social presence [47]. There is utility in using VE to practice social interactions; but VE has not yet supported mastery in face-to-face interactions.

Shared physical environments, such as interactive computer games on tabletops and tablets, have been shown to support social interactions for collocated users. For example, MOSOCO [12] is a mobile augmented reality system that provided step-by-step guidance for face-to-face social skills, including proximity. This work demonstrated the importance of interaction immediacy [45], often prompted by physical nearness, in the dynamics of social interactions. Our work goes beyond MOSOCO's simulated system to detect proximity with a single user functional prototype.

Wearable devices can deliver information in real-time, face-to-face interactions—a best practice for learning social skills, which are best learned in real-world scenarios [48]. To support the generalization of skills, researchers paired a mobile computer with a wearable device (combined with camera and other sensors) to record and analyze facial expressions and head movements of the person with whom the wearer is interacting. This research indicates that these systems are successful in providing actionable information

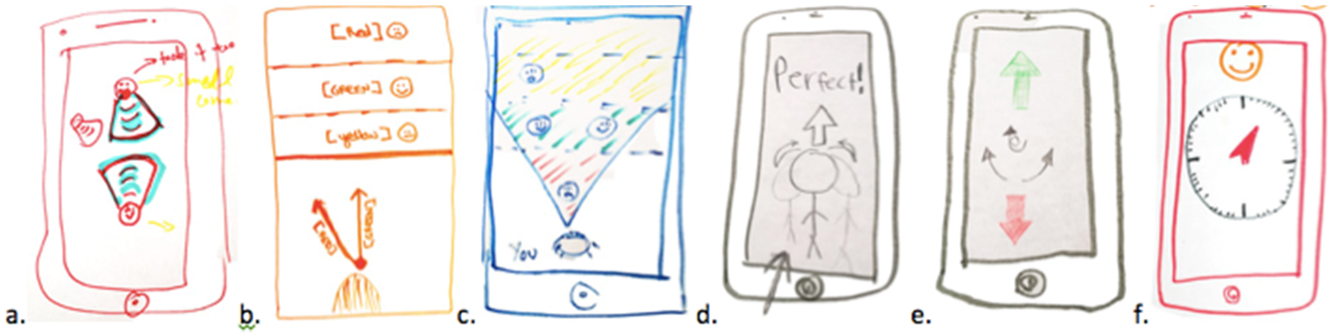

Figure 2: Interfaces designs from parallel design activity

to support understanding of emotions in others for children with autism [25,32]. More broadly, wearable technologies can assist the growing number of individuals diagnosed with autism in perceiving communication in a natural rather than a structured environment (e.g., [7]), bootstrapping their ability to learn and develop in social settings with privacy and autonomy. We extend these projects by providing single-user self-awareness of nonverbal communication through proximity.

DESIGNING FOR PROXIMITY

Social rules of interaction are dynamic, context-sensitive, and often hidden [37]. Usable technology to reveal this dynamic context must be designed with an understanding of norms for interpersonal space and precise measurement. Likewise, a comprehensible interface must provide information precise enough to avoid violations of interpersonal space. This requirement is complicated by the reality that even a slight change in body position or closeness can dramatically change the interpretation from friendly to dominating [16]. At the same time, these precise measurements must be representable, comprehensible, and actionable for a person with autism during a live interaction. We used parallel design [38] with children and adults to inform our designs. We then developed a functional prototype to test a subset of these design concepts, first with a design partner with autism and then through a larger feasibility and validation study as described in the next section.

Parallel Design

We conducted parallel design sessions with six adults and five typically developing children (ages 9-11). Participants were selected by accepting an invitation to volunteer to draw at a departmental graduate student social event at our university and in the first author's community-sporting event. The designer group was told to design a interface for a mobile phone that will communicate interpersonal space to be used for children with social skills challenges, then the six adults made drawings simultaneously but independently. The lead author privately asked for a quick explanation upon collecting each drawing. The typically developing children in the targeted age range were asked one by one to draw a screen to help other children with special needs understand "when they are not facing a person or standing too close or far."

We collected eleven sets of designs from participants, totaling 65 sub-components (e.g., widgets, screens, and so on). We analyzed designs with attention to the repeated components for insight into the group's thinking about interpersonal space. We evaluated each design component and the designs as a whole to identify central themes and outliers that make up metaphors [42] about interpersonal space. Two members of the research team analyzed each component separately in form and concept. They then met together to group common and diverse features from among these sets. From these groupings, the most common features were identified. The larger research group discussed and compiled a list of design concepts and then translated them into the interface design of a functional prototype.

Four primary themes related to face-to-face interactions emerged from the parallel design sessions: precise measurements, zones of proximity, direction and movement, and type of awareness feedback. Porting physical measurement tools into the virtual space was a common design choice for proximity. Regarding feedback, participants tended towards providing judgment or providing awareness, using colors or text. For example, some designs included text reading "Perfect," or green and red arrows indicating that the user should move or go in the green direction (see Figure 2d & 2e). Research on wearable systems indicates the importance of rapidly comprehensible information to support the ability of a single user to privately access a tool before, during, or after a face-to-face conversation [41]; therefore an emphasis on quick and accurate information became central to the development process. We combined the most salient design features with the technical requirements of a wearable system to develop a functional prototype.

Precise Measurements

Porting physical measurement tools into the virtual space was a common design choice for proximity, though less so for orientation. Visual references of common real world measurement tools can aid in the comprehensibility of a sensing system that is likely to be unfamiliar to its users.

Nearly all of the designs included a notion of “zones” indicating ranges of appropriate personal space and orientation. Specifically, nine elements illustrated distinct areas or zones to indicate multiple spaces between people, suggesting there is a range of spaces associated with proximity (see Figure 2a, 2b, 2c, & 2f).

Without discussing each other’s designs, participants demonstrated consensus about the relative size and number of zones—personal space, a social space, or a space beyond an interaction. These zones are similar to but not the same as the four zones from the literature (see Figure 1). These components then became central to our final design.

Motion and Directionality

Designing for appropriate proxemics behavior requires a basic understanding of individual users’ proximity and orientation. The social proxemics literature indicates that there are thresholds that when crossed convey a change in the interaction. For example, moving across the personal space threshold is detectable and becomes uncomfortable within 45 centimeters of a person [2]. Therefore, any assistive technologies in this space must be sensitive to changes as small as 10 centimeters at the personal and social boundary. This level of accuracy can be challenging for wearable systems. In particular, most that are that sensitive (e.g., [49]) cannot be mobile, and most that are mobile (e.g., [46]), are only accurate at 30 centimeters or greater.

Although we did not ask participants to explicitly consider motion in their designs, nearly all (9 of 11) explicitly addressed whether the user was observing or approaching others or others were approaching the user, such as the use of arrows or dials pointing towards or away from the user (see Figure 2b, 2d, & 2e). This result indicates that any sensing system we might employ to support social proxemics should update rapidly, at least as rapidly as most people walk when approaching someone in a social setting, and the visualization of those sensor readings must indicate directionality and support prediction of future proximity and orientation.

Feedback: Balancing Judgment with Awareness

We gave no explicit instructions to the design participants regarding how they might convey information regarding proximity and orientation. However, the methods exhibited by the participants tended towards either providing judgment or providing awareness, with some limited overlap between these categories. In terms of judgment, people used a variety of approaches to convey when the user is doing something “right” or “wrong.” Even in the case in which the participant used a physical metaphor (the compass, as described above), this feedback also included emoticons as a means for providing additional feedback (See Figure 2f).

Holistic View vs. User Perspective

Given the prompt to design a tool to support individual awareness of proximity, it is perhaps surprising that the designs tended to use an overheard view of the scene (9 of the 11 designs) rather than a first person perspective (at ground level, 2 of the 11 designs). An overview perspective suggests an understanding of space that extends beyond the immediate interaction and could extend to other kinds of environments, such as a party or other larger group gathering. A “street level” approach would be closer to the user’s actual experience and interpretation and may have its own benefits. However, this approach would likely limit understanding to that interaction. In discussions, participants in the design study described grappling to some degree with this decision and ultimately modeling it on an overhead view. This choice connects closely to the default design pattern for online mapping applications, which may have had some influence in professional designers’ views. The children participants, however, did not have the same experience with these kinds of applications, suggesting that more investigation may be needed to unpack the differences in these views. Regardless of the specific view chosen, research indicates the importance of rapidly comprehensible information to support the ability of a single user to privately access a tool before, during, or after a face-to-face conversation [41].

Functional Prototype

To more deeply understand the four themes from our parallel design sessions and demonstrate the feasibility of this approach, we created ProCom, a prototype system that includes a wearable sensor module and connected mobile application[24]. In this section, we describe the technical implementation of this system and evaluation of the system demonstrating that it works as expected.

Determining Relative Distance

Building on the requirements uncovered in our design study, we narrowed the range of view on the interface to 90 degrees to capture the person directly in front of the wearer. This also limits the challenges imposed by other passersby to the system’s interpretation.

We define directly forward as 0°. Center-left angle is represented by a negative number, and center-right angle is represented by a position number, so the IR sensors’ view should be $\boldsymbol{\theta} = \{\theta_1, \dots, \theta_{91}\} = \{-45^{\circ}, \dots, 45^{\circ}\}$. When users turn on the system, IR sensors periodically sweep back and forth between -45° and 45°. In each step, the IR sensors rotate 1° and get a distance value. For every period, we obtain a data array s that contains 91 distance values $s = \{d_1, \dots, d_{91}\}$, which is the distance from the sensor to surrounding objects, and the global minimum value indicates the nearest object to user. Then, the system uses a Mean-Filter with a window length $L_{win} = 5$ to remove noise, getting $s' = \{d'_1, \dots, d'_{91}\}$.

The global minimum distance d_i' in s' indicates the distance to the interaction partner will be θ_i. This configuration allows for the measurement of relative distance without additional work or opting in on the part of a potential interaction partner for the purpose of a feasibility experiment. One limitation of this approach is that other people who are not the primary target of a social interaction but are between the user and the partner may disrupt the sensors. Similarly, a room crowded with furniture and unmapped by the system could pose challenges. These are both issues we leave open for future work.

Visualizating Data on the Move

The ProCom mobile interface includes an aerial view with the user depicted at the bottom and concentric slices of a wedge to represent proximity zones, which represent the normative distance for social interactions (see Figure 3).

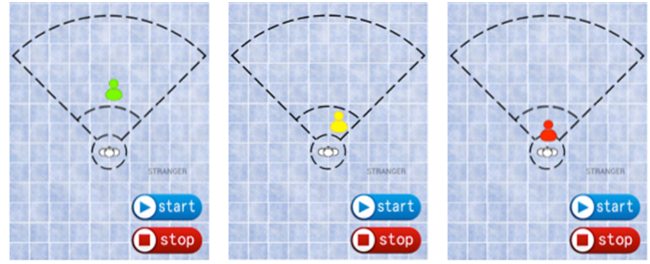

Figure 3: ProCom's three interfaces for green, yellow and red zones of social proximity. The outlined wedge shape provides boundaries for face-to-face body orientation.

Specifically, ProCom shows the change in proximity as two people get closer, in this case two acquaintances. The green zone is a good comfortable social space at a distance from the user of 120 to 370 cm. The yellow (45 to 120 cm) is getting too close, and the red zone is much too close for an acquaintance at 45 cm or less. These zones represent the space of a person in a vis-a-vis formation (90°), one of two most common formations for pairs of people in a social interaction [19,26,33]. The zones are customizable depending on the level of intimacy the user has with another person, but in this implementation we focused on stranger or new acquaintances to test the viability of the system.

Accuracy of Distance Measurement

To validate the accuracy with which ProCom measures distance, two research participants stood face-to-face in a 6 x 6.5 m^2 room, while one of them was wearing the ProCom box on his chest. We then changed their relative distance d by 5 cm at a time from 20 to 400 cm, $d = \{20, 25, \ldots, 400\}$. For each distance condition, we collected 20 results from our system, and then calculated the maximum, minimum, and mean value of 20 results. Our results indicate that ProCom can provide distance results with high accuracy. Bias values grew in our experiments as distance increased. However, even with these errors at larger distances, ProCom still maintained accuracy within 15 centimeters, an appropriate level of variation for therapeutic interventions. Moreover, when distance was less than 100 cm, ProCom performed more stably with bias less than 5 cm.

FEASIBILITY STUDY

In our final design exploration, we used ProCom in an experimental style feasibility test of our approach. To reduce the burden on children with autism and their families in participating in research, we had relied on our combined decades of experience with children with autism until this point in the research. At this point, however, we explicitly recruited children with autism to understand how they might interpret and act on the visualizations, to validate the technical validity of the system with this population, and to uncover design considerations we had not encountered previously. To scope our question about behavior change, we explicitly aimed to assess the association between using the intervention and the likelihood that participants position themselves a normative distance from the volunteer during the social interaction with a new acquaintance. Although we considered different contexts and designed the tool to be dynamic by creating different color schemes for each relationship type *(i.e.,* family, friend, acquaintance, and stranger,) we only tested the acquaintance relationship in the lab as this case is most commonly described as problematic by families and educators. To unpack specific design considerations, we observed children interacting with ProCom and discussed these interactions with them and their parents following the sessions.

Participants

Participants were recruited through fliers distributed to local services agencies and on Facebook. The fliers advertised a "study using wearable systems detecting interpersonal space." Parents contacted the first author to gather more information and set up a time to run the study. Mothers and occasionally siblings were present during the trials that took place in a large open indoor space. Ten children with autism (ages 7-14, 7 boys) participated in individual one-hour study sessions. The hour included the experiment as well as child and parent interviews. Participants demonstrated a wide range in verbal abilities during the sessions, with some participants not using verbal communication during the session (P4), to providing one or two word responses (P1, P2, P3, P5, P8) to highly verbal (P6, P7, P9, & P10).

Methods

After parent consent and child assent, each child was assigned to four control (no phone) and intervention (with phone) trials in randomized sets of two. Then, the first author, a Board Certified Behavior Analyst, delivered a brief social skills lesson focused on the zones of interpersonal space to introduce the purpose of the system and create a shared baseline. The first and second author showed the children how to use the system. After this brief introduction, the trials began, and we randomly alternated which condition came first for each block of "no phone" and "with phone" trials across four blocks.

During each trial, participants stood with the researcher at the start point (500 cm from a stationary volunteer). The trial would then begin when the participant was told they could start. During the control trials, the researcher touched the start button on the phone as the participant began to walk toward the volunteer. In the intervention trials, the participant started the app on the phone when they were ready and proceeded to walk.

The research volunteers were asked to remain in place without shifting their bodies and to wait to speak until the child initiated the interaction. The trials ended when the participant indicated they were done or at 30 seconds, whichever came first. Trials were video recorded for comparison to the log data.

After each trial, the mother and the volunteer independently completed a Likert scale to assess proximity in the context of each trial (-2 = "too close", -1 = "a bit close", 0 = "just right", 1 = "a bit far", 2 = "too far"). Parent and research volunteer ratings of proximity were compared to each other and to the data we collected from the sensor to determine the social validity of the system's proximity measure.

After all trials were completed, the child and mother were interviewed for up to 30 minutes. These semi-structured interviews consisted of asking the parent and child together what they thought of the study, and the system.

Findings

Overall, ProCom's measurements of proximity agreed with both parent and volunteer ratings, indicating that the system effectively measured proximity within the normative cultural context in which it was designed to work. However, the likelihood that participants would stand in the "acceptable" (green) zone varied across trials and participants. Four of the nine participants stood in the green zone in the "no phone" control condition; the 5 who stood outside the green zone in the control condition showed medium effects in terms of improvement as we discuss below. All parents but one reported that the system could have been helpful to teach interpersonal space to their children in their daily lives.

Effectiveness of the System to Change Behavior

We captured the proximity measurements from the sensors (1 event for ~1 second) for each of the 60 trials. To verify the measurements for reflecting the proximity between the child and the researcher, we hand coded the video and correspondence to the log data (Inter-Observer Agreement 96%). Approximately 20% of the proximity measurements within the "first stop" to "end" time intervals were marked as invalid due to the system malfunction or interference (*i.e.* the participant put his or her hand in front of the sensor). None of Participant 8's log data was captured due to a battery charging error.

Next, we viewed the video recording of each event to determine the first point at which the participant stopped as the starting point for the interaction. On average participants spent the first 10 seconds of the trial walking toward the volunteer. We concluded each trial at the end of 30 seconds or the child terminated the interaction by walking away, turning toward researcher or parent, or otherwise indicting they were done with the trial (e.g., for one trial P2 said "cut" to end). Then we compared log data to the video and removed events with interference. Despite limited lost data, we have adequate information to make our claims. Lost data occurred when the child stood sideways or held the phone in front of the sensor. Even with these

ID	Age	Gender	No Phone Mean in cm	Avg. Volunteers Rating (-2 to 2)	Avg. Caregiver Rating (-2 to 2)	With Phone Mean in cm	Diff in Means	% of green trials by condition
P1	7	M	130	--	--	110	-20	100/50
P2	11	M	62	--	--	67	5	0/0
P3	12	M	120	--	--	143	23	50/100
P4	14	M	125	-0.37	-0.62	164	39	25/50
P5	11	F	26	-2	-1.5	33	6	0/0
P6	8	F	94	1.5	0.68	132	38	25/50
P7	7	M	167	1.5	0.87	162	-6	100/100
P9	8	M	165	1.5	0.87	171	5	100/100
P10	8	M	242	1.42	1.42	259	16	100/100

Table 1: Participant demographics and results from log measurements and human raters.

occasion events, we were able to collect 15 measurements to average after the participant's first stop.

We calculated the average distance during each trial and compared no phone sessions. Four participants demonstrated proximity in the green zone during the no phone trials (P1, P7, P9, P10), and three maintained proximity the green zone during from trials (P7, P9, P10)—thus generally demonstrating that participated distance who are already exhibit expected proximity maintain this distance while using the ProCom system. The four participants that demonstrated proximity in the yellow zone (a bit too close) without the phone, moved into the green zone with the phone, doubling the number of sessions they averaged the green zone proximity. The one participant (P5) that was in the red zone without the phone remained fair with the phone although she did have an increase of 6 cm toward the green zone and treatment trials (see Table 1). In terms of changing zones, five participants remained in the same zone, one moved unexpectedly into the yellow zone from the green zone, and three performed better moving from the other zone into the green zone. From these data, we conclude that participants who stand in the yellow zone can be encourage to stand in the green zone as we see P3, P4, and P6 change their average distance by stepping back 23, 93 and 38 centimeters respectively.

Additionally, to explore the social validity of physical measurement of proximity *in situ,* we surveyed parents and volunteers after each trial. We averaged the parent and volunteer ratings per participant by condition (see Table 1). Parent and volunteer independent ratings were highly correlated, indicating they agreed with each other on the specific level of proximity ranging from too close to too far (r =.83, $p < .01$). This high correlation confirms there was a shared understanding of what a comfortable social distance should be for each interaction. These distances also corresponded to those ProCom was reporting, indicating shared understanding of these cultural norms with the system (r = .86, $p < .01$).

Actionable and Usable in Everyday Life

Given the cognitive and emotional differences many children with autism experience, we were particularly concerned in this work that the device be actionable and easy to comprehend. Six of the participants (P3, P6, P7, P8, P9, P10) were able to use the system immediately, glancing at the phone and stopping in the green zone (see Figure 4d). They also looked during the interaction and adjusted positions when they stepped into the yellow zone. When the trial ended, they glanced again. These behaviors support the design concept of providing dynamic visualizations and demonstrate ProCom's feasibility.

Some participants articulated their understanding of the interface (*i.e.,* P2 and P3 both mentioned that the colors changed as the person moves). P6 noted that the system "*tells you to stop, you can see,"* adding "*it started out a green and it stops being green and it went to red and I backed up.*" P10 said for him that ProCom "*answered questions about closeness and told him to back up a little bit.*"

Parents expressed understanding of and interest in the system. For the children who did not seem to demonstrate a need for the device in the lab (i.e., they were in the green zone in the control trials), all but one parent still expressed interest in using ProCom in day-to-day activities.

"*I want them to know not to stand too close because it's annoying the person in front of you and they're going to be like 'back up' but it's not something they are motivated to care about. They've never really been motivated to care, I care – but they don't. I don't want to have to constantly tell them, you know remind them. With (ProCom) they're still getting feedback – instead of having the person talking about it. Just them being able to learn it without me having always tell them."* - mother of P6 & P7

Likewise, the mothers of those who did show a need also confirmed a desire to use such a system.

"*I feel he doesn't know how close to get or how to close not to get. Its like an abstract idea for him… walking between spaces or Disneyland or anywhere you're trying to walk through a group, it's like he's not even aware that he walked in through them, that's how low his proximity compass is."* The mother of P1 expressed the relief such a system would have been when her son was first learning this skill: *"If we had a system like this, then maybe it would've been easier maybe, it would've been much more short-lived perhaps. Maybe we would be less stressed out because behaviors like that prevent us from going out to a lot of public places."* – mother of P2

All the children stated that they liked the ProCom system, with a few caveats. For example, a 12-year-old boy (P3) said "*it was really cool but creepy how it knows where you are*." P7, an 11 year-old girl, was concerned over the impression that others may have of the system being used for surveillance. She explained her concern about what others would think of her wearing a sensing system. She suggested "*If you made like a decorative belt and made little dots this size, it would actually look like a belt so it doesn't look like you're spying on everybody*." These "creepiness" and "spying" concerns indicate that children with autism are concerned about the acceptability and impact of these devices on others and should be helped to explain why and how systems work in addition to supported in using them directly.

Challenges of Novel Technologies for Intervention

Novel technologies provide immense opportunities for interventions. They can, however be problematic, especially for vulnerable populations such as ours.

Three participants (P1, P4, & P5) started walking towards the conversation partner but then turned away to explore the system instead of interacting (see Figure 5b). During the time for conversation, these participants attended to the system only by touching the screen, watching or touching the sensors, swinging the sensors, or shaking the phone. This result implies, perhaps unsurprisingly, that some time may be required for children to adjust to a technology as novel as this one before an intervention may take effect.

Similarly, for four participants, the research team and parents needed to do additional work to ensure the child's comfort while using the system. For example for P8, the mother spent several minutes acclimating her daughter to wearing the system by describing its parts and actions and letting her observe her mother handling the system that makes a soft swishing noise when the sensors are turned on. P4 and P5 took off or turned off the system between trials. Another participant put his fingers in his ears during the trials with phone trials (see Figure 5a) after which his mother said "*I'm so proud of you because you tolerated that on your body. [then addressing researcher] Not too long ago he wouldn't have been able to do it." – Mother of a 7 year old boy (P1).*

These results indicate that wearables, while opening new possibilities, provide additional challenges to overcome for this population. In particular, researchers and designers must consider all of the potential additional sensory and attention challenges inherent to the device when creating it and when developing an intervention that uses it.

Enlisting Collaboration

As a social tool, we hoped that ProCom would support proximity awareness and improve social interactions. As a novel tool, however, some participants also made it collaborative or used it as a means for socializing further.

Two participants commented about ProCom to the conversation partner. A 12 year old boy (P2) gave ProCom a name and introduced it to his partner upon approaching by saying "*Hello, this is Otto.*" Another 12 year-old boy stood side by side with the volunteer (see Figure 5c) and held the phone between them to share its interface.

In an alternate style of cooperative use, some mothers supported their children during the trials by intervening when their children became disengaged from the conversation or started playing with the system. When P1 disengaged with the conversation partner, his mother called to him after the trial with suggestions of what he could say by talking during the trial and saying, "*Ask him what his favorite dessert is."* These parent prompts were common for the few children who became distracted by the technology during the trials.

These results enforce the idea that even a system explicitly built for a single user can be co-opted to be cooperative. An open challenge then, in this particular case, is ensuring that the children feel autonomous and empowered enough to use the system alone while also comfortable enough to share it when they choose. Similarly, some parents wanted additional feedback about the child. As a different kind of collaboration, these shared data might enable collective reflection within families.

DISCUSSION

We explored three design activities to support a wearable system for social proximity: parallel design sessions; probed a functional prototype with an adult with autism; and feasibility study with children with autism to explore proximity during a real-time interaction. Testing the design choices to create a dynamic visualization shows us that children with autism respond to real time information during a conversation. Some participants explored the visualization dynamically to adjust their proximity while engaged in conversation and others explored the technology at the cost of the conversation. In the cases during which the child disengaged with the volunteer, parents intervened to prompt their children to stay engaged—leaving open questions for design. It may be unreasonable to expect every wearable system to be immediately usable by every person, especially within neurodiverse communities. However, the need for wearable systems to be useable for a range of abilities is emerging [11]. The popularity of wearables to support health goals is rising, bringing challenges in extending to designing for children.

One way to support the uptake of wearable assistive technology is to consider "step up" versions of systems to support learning. Prior literature in personal informatics indicates three phases of use: understanding the collected data, reflecting on it, and taking action [30]. This "stage-based" approach is complicated in wearable assistive technologies for children, because caregivers often initiate use of a system and are interested in behavior change. Meanwhile, the users may not be motivated to use the system or have an understanding of its purpose. Therefore designers could support an initial "ramp up" phase to assist parents in teaching their children to use the system.

Ramping Up through Collective Use

Learning to use wearable assistive technology could involve verbal, gestural, or physical prompting to teach a user how to check one's position in relation to others and reference the feedback from the system. Although children receive ongoing prompts from others in day-to-day life, the choice to respond or not to respond to the information on a dynamic screen is left up to the user. Users who depend on others, either conversation partners or parents are engaged in a collaborative experience. Dependent users gain support from those who understand the purpose of the technology is assistive (*i.e.,* parents, therapists, conversational partners) [40]. Therefore, designing for assistance suggests designing in a way to make the support needed visible enough to enlist others to collaborate in achieving the social task when needed.

A collaborative approach could reduce the work the parents do to prepare their children to use a system due to sensory sensitivities. A ramp up mode could be designed to support the systematic de-sensitization parents use to support a child in adopting a new tool. Once a system is comfortable and comprehensible, the motivation of the child to use the system becomes a primary issue. Supporting motivation of the primary user might involve building in extrinsic rewards (*i.e.,* point systems) thus supporting parent and child. Designers could add in a mode with extrinsic motivation to support independent use.

Lastly, consideration of the social context during the use of the system will impact the possible concerns associated with assistive devices. Once the system can be used independently, the invisibility may become preferred as the users may choose to explore less familiar settings. Once a user is independent, then the visibility of the system and co-users can be minimized. This reduction in visibility could reduce the self-consciousness (*i.e.,* not wanting to appear as if they are spying on others) the child may feel when use is obvious to others.

Limitations

As a functional prototype, ProCom was limited to a specific use. We created one context for students to approach an acquaintance and stop when they chose to engage in conversation as an ecologically valid interaction. We designed for a face-to face-interaction up to 90 degrees; yet we did see other formations and presented them in Figure 5. A future version of the system could capture 180 degrees or more to make use of these contexts as well as support for customization of the zones.

Customizing for individual needs and family preferences was mentioned frequently during test sessions. This request is consistent with literature regarding the potential for stigma associated with wearing assistive technologies [40,43]. Many of our interviews focused on how this system could be used outside the lab. Parents suggested making the sensor watch sized or in a hat to minimize its appearance. One parent added she wanted it to be fashionable for her daughter to wear it. This work is limited by not including children with autism in the design of the system; however future work will look at customization and supporting ways to express one's choices and preferences for interpersonal space.

CONCLUSION

For people with autism to use a system to develop proximity awareness, that system must be available anytime anywhere and in any environment, function without explicit participation from others (unless in a training phase), and be private and unobtrusive. No existing proximity detection systems met these requirements, leading to our iterative development of ProCom. However, this is just a first step toward developing a truly accessible and adaptable intervention for supporting proximity awareness.

Our work is built on clinical literature, our experience over many years of developing social skills interventions for people with autism, our parallel design study, an experiment with an effective functional prototype and parent interviews that show the potential utility of such a system. We have demonstrated that this system's design is usable, comprehensible, and effective in supporting awareness of interpersonal space for people with autism. Additionally, although our work demonstrates that an approach using mobile, sweeping, dual IR sensors is in fact technologically feasible and accurate in an experimental setting, more work is needed to ensure that this approach would be reasonable for long-term use in everyday life.

In this work, we explored the fundamental challenge of understanding and using interpersonal space for children with autism.

Our design explorations in interactive visualization allowed individual users to sense and reflect on their proximity. Some users could engage with the system seamlessly while maintaining a social interaction, others required assistance. This work contributes to design insights about wearable assistive technology by demonstrating that this approach is technically feasible, and immediately effective. By understanding the impact our design choices had on interactions, we open a new design space for single user proximity sensing.

Future directions for design could be to consider could consider the generalization of the procedural knowledge introduced here as well as adding features to enlist the support of one's immediate environment, shifting the burden or consequences of not following the norm to the group. This is particularity challenging as this requires not only revealing an atypicality in oneself to a conversational partner, or in the current interaction, but also lacks a way to share this confidential information, as well as determine strategies to address the problem, not any of these factors are well understood.

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