Wearable Technology Design for Autism Spectrum Disorders

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Abstract

Background Wearable technologies have the potential to increase the quality of life and wellness for individuals with ASD and their families. However, there is a lack of research on WT for ASD and no research on understanding users. Thus, this interdisciplinary research was conducted to understand important design factors and preferred functions and design attributes for WT for ASD to guide the design process in the early-stages, and to develop and evaluate a WT prototype for ASD.

Methods Individuals with ASD and their parents who are the potential users were recruited through purposive sampling. The data were analyzed through color-coding, major theme extraction, descriptive analysis, and a series of Welch's t-tests. A prototype was developed and evaluated based on the defined preferred functions and design attributes and design factors.

Results First, the results about demographic backgrounds, prevalent symptoms, challenges in daily life, and user experiences related to WT were defined. Second, 12 important design factors of WT for ASD were identified. Third, individuals with ASD and their parents' preferred WT aspects on item types, functions, and design attributes, expected use frequency, use occasion, and data notification were identified. Lastly, a prototype was developed based on the results and evaluated for the future development of WT for ASD.

Second, two groups were categorized according to the type of YOLO-disposition (high or low).

Third, a well-being lifestyle based on a disposition type showed some significant differences in terms of both mental and physical health. Consumption value showed some significant differences in terms of differentiated value and social value.

Conclusions The results are expected to help designersin the development process of WT for ASD and ultimately benefit individuals with ASD and their families and caregivers.

Keywords Design, Development, Wearable Technology, Autism

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1. Introduction

Autism spectrum disorder (ASD) is a developmental emotional and behavioral disorder defined by deficits in social interaction and communication, including restricted, repetitive, and stereotyped interests and behaviors (Bölte, Feineis-Mattews, & Poustka, 2008; Hubert, Wicker, Monfardini, & Deruelle, 2009; McCraty & Zayas, 2014). Many individuals with ASD (IASD) have difficulty understanding their emotional changes and regulating their behavior sometimes in social situations (Bölte et al., 2008). ASD occurs in approximately 1 in 68 children, 1 in 42 boys and 1 in 189 girls (Centers for Disease Control and Prevention-CDC, 2014, 2016). ASD symptoms can be reduced by treatments and appropriate interventions (Estes et al., 2015). However, ASD is associated with high lifelong care costs; the annual medical costs of ASD in the U.S. are anticipated to be $200-400 billon by 2024 (Government Accounting Office, 2006; Shattuck et al., 2012). IASD and their families may have limited access to professional care because of high costs, waiting time, and traveling distance (Goodwin, 2008).

One way to improve quality of life for IASD is through wearable technologies (WT), which can decrease medical costs through unobtrusive monitoring of health conditions and well-being and provide patients more freedom (Park & Jayaraman, 2003). Despite the potential of WT for IASD, few researchers have investigated preferences of IASD and their families on product designs and functions, which are critical for user acceptance (Sinohara & Wobbrock, 2016). The lack of understanding of user preferences and design factors has led to limited functions, problems with usability, and inappropriate designs (Shinohara & Wobbrock, 2016). Thus, the purposes of this study were: 1) to understand important design factors and potential users' preferred design features for WT for ASD to guide the design process in the early stages; and 2) to develop and evaluate a prototype of WT for ASD based on the defined preferences of design features and important design factors. This interdisciplinary research was conducted in collaboration with researchers in apparel design, psychology in ASD, and biomedical engineering. The results will helpdesigners in developing WT for ASD and ultimately benefit IASD, their families, clinical professionals, and educators.

2. Literature Review

Literature reviews were conducted on three areas: a) ASD symptoms to understand ASD and their needs and wants; b) design factors for WT for the survey preparations; and c) WT and wearable products for ASD to investigate what technologies and products are available.

2. 1. ASD Symptoms

In the 1960s and 1970s, ASD was treated as a severe disorder or disability (Christensen, 2016). In the 1990s, the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) presented diagnostic criteria for a number of related disorders, including autistic disorder, childhood disintegrative disorder, and Rett's disorder (American

Psychiatric Association-APA, 1994; Christensen, 2016). In 2013, the fifth edition of the DSM (DSM-V) redefined ASD as a single disorder (APA, 2013; Christensen, 2016). For this study, two groups of participants were recruited: individuals diagnosed with ASD (IASD) according to the DSM-V or with autistic disorder or Asperger's disorder according to the DSM-IV; and parents of IASD (PASD) who have lived with IASD and played a role as caregivers. It is important to interview potential users about their preferences for designs and functions, and about their challenges in daily life with their disabilities (Carroll & Kincade, 2007). Thus, the two groups of users for the study were IASD and their parents who had observed and lived with them long-term.

Many IASD have difficulty with monitoring and awareness of their own emotional state, as their capacities for sensing and interpreting internal physiological cues can be impaired (McCraty & Zayas, 2014). The common symptoms of ASD are social deficits, language impairments, and repetitive behaviors (Dominick, Davis, Lainhart, Tager-Flusberg, & Folstein, 2007). Social deficits include difficulties with everyday human interactions, such as missing social cues or inability to predict or understand others' behaviors (Autism Speaks, n.d.; Dominick et al., 2007). IASD commonly show significant language delays or are nonverbal (Dominick et al., 2007); and IASD tend to show unusual repetitive behaviors or become obsessive about numbers, symbols or other specific topics (Autism Speaks, n.d.).

Related neurological issues for IASD include a) sleep deficits; b) mood and anxiety problems such as unexpected arousal, anger, or depression, or difficulty with self-awareness and self-adjustment; c) Attention Deficit Hyperactivity Disorder (ADHD); d) seizures, which occur in about 39% of IASD; and e) sensory processing problems such as hypersensitive or hyposensitive (Autism Speaks, n.d.; Dominick et al., 2007).

2. 2. Design Factors for WT

To understand what aspects users would consider when purchasing and using WT for ASD, a literature review was conducted on extant research in the areas of ASD symptoms and treatments, wearable technologies for monitoring body signals, and product development for ASD to understand the aspects that designers need to consider when developing WT for ASD. The important design factors that researchers suggested and pointed out in the extant research were extracted. The derived important design factors are: safety, data accuracy, comfort, flexible material, portability, durability, reasonable price, ease of use, lightweight, small, unnoticeable design, and unique design. These design factors are defined in table 1

Table 1 Definitions of design factors

Design factors	Definitions
Safety	–The WT does not put the wearer at risk for any physical or psychological harm (Buenaflor & Kim, 2013; Hartman, 2014), and keeps data private and secure (Pantelopoulos & Bourbakis, 2010).
Data accuracy	–The data collected by the WT is accurate for proper use and understanding by the wearers (Kaye & Crowley, 2000).
Comfort	–The WT is comfortable to wear (Buenaflor & Kim, 2013; Hartman, 2014; Knight & Baber, 2005).
Flexible material	–The WT is made of flexible material (Gómez et al., 2008).
Portability	–The WT is portable and easy to bring anywhere (Lukowicz, Kirstein, & Troster, 2004).

Durability	–The WT is durable for frequent and long–term use (Hartman, 2014).
Reasonable price	–The WT is in reasonablypriced (Anderson & Lee, 2008; Ariyatum et al., 2005).
Ease of use	–The WT is user–friendly and easy to learn (Pantelopoulos & Bourbakis, 2010).
Lightweight	–The WT is lightweight to encourage frequent use without fatigue (Knight & Baber, 2005).
Small	–The WT is small (Koo et al., 2016).
Unnoticeable design	–The WT does not interruptwearers' everyday activities and not highly noticeable (Buenaflor & Kim, 2013; Pantelopoulos and Bourbakis, 2010).
Unique design	–The WT is aesthetically appealing (Anderson & Lee, 2008; Ariyatum et al., 2005).

2. 3. WT and Wearable Products for ASD

In addition to the extant research, WT and wearable products for ASD were investigated through an online searching tool and used the keywords of autism, ASD, or autistic and wearables to find product development cases. The products were reviewed to explore available types, functions, and designs in the market, and to guidethe survey question developmentsoftypes, functions, and designs that people prefer to use.

2. 3. 1. Aids for calming and relieving

The first type of helpful technology for IASD is clothing and WT to relieve and calm the wearer by adding weights and pressure, minimizing sensory distractions, controlling temperature, and using soft fabrics. Adding weights. Kozie Clothes developed a vest with three weights placed inside the pockets to calm the user (Kozie Clothes, 2013a). Adding pressure. Calming Clothing is designed to calm autistic children by creating feelings of security and body awareness with various stretchy garments, made of spandex blended cotton, that that apply pressure to the wearer (Calming Clothing, 2016). BioHug Technologies' BioHug Vest is a similar garment that uses duration, location, and intensity of pressure to calm the wearer (BioHug Technologies, 2016). Inflatables. Sensewear jacket has an inflatable lining that produces calming pressure for users, and the pullover hoodie creates a personal acoustic chamber (Rhodes, 2015). T.Ware's T.Jacket uses an automatic air-pump system to create touch pressure to calm down wearers, tracks user's activities through embedded sensors, and transfers the data to an app (T.Jacket, 2016). Minimizing sensory distractions. Wearable Therapeutics' Snug Vest also has a hoodie detail that blocks out light and overwhelming distractions for IASD (Wearable Therapeutics, 2013). Beagle is a hooded scarf embedded with sound reduction, audio integration, aromatic stimulation, and tactile customization technologies to stimulate or dampen users' senses (Leo Chao, 2008). Controlling temperature. Kozie Clothes uses temperature control as well as pressure to induce calm feelings. For example, their long-sleeved t-shirt is infused with smart phase change material (PCM) to balance temperature (Kozie Clothes, 2013b). Using soft fabrics. Independence Day Clothing is a line of soft-textured clothing designed without buttons, zippers, or laces to make it easier for IASD to wear (Independence Day Clothing, 2016).

2. 3. 2. Aids for physiological awareness and task management

The second type of aids increases wearers' awareness and helps manage their behaviors. This type can be further divided into aids for physiological awareness and aids for task managements. Clothing and other wearable devices embedded with fabric-based sensors can help IASD understand physiological and emotional changes and increase their self-regulatory capacity. For example, by allowing users to recognize strong sensations and emotions with real time visual and auditory feedback before they become over-stimulated. These devices can monitor emotional changes by measuring users' heartbeat variability (McCraty & Zayas, 2014) and skin resistance (Hubert, Wicker, Monfardini, & Deruelle, 2009). For example, Awake Lab's Reveal can predict meltdowns by tracking anxiety symptoms through heartbeat, skin temperature, and sweat levels (CBC News, 2015). Watchminder 3 uses positive reinforcement to help users improve their learning and time management behaviors. It vibrates to remind the user to pay attention, participate in class, submit homework, and manage time. (Watchminder, 2015).

2. 3. 3. Aids for communication

The third type of aid assists IASD is improving communication. Smartstones Touch helps IASD communicate through patterns of lights, vibrations, and sounds (Smartstones, 2015). AbleNet's TalkTrac Speech is a wristband device that can record and play messages to assist users with communicating in conversations (AbleNet, 2011). Brain Power has experimented with using Google Glass to aid social interaction, assisting users with skills like understanding facial expressions and eye contact (Brain Power, 2015).

2. 4. Research Questions

Understanding potential users' preferences on functions and designs is the key for developing new products that will succeed in the market (Carroll & Kincade, 2007; Sinohara & Wobbrock, 2016). Based on the literature reviews, the following research questions were proposed: (1) What important design factors should designers consider when developing WT for ASD? (purpose 1); (2) What IASD's and PASD's preferences on functions and design features for WT for ASD? (purpose 1); and (3) How can these defined preferences and important design factorsbe applied to develop and evaluate a WT design for ASD? (purpose 2)

3. Method

3. 1. Sampling and Data Collection

After receiving the IRB approval, the participants were recruited through purposive sampling. Carroll and Kincade (2007) suggested developing a wearable product for people with disabilities considering various symptoms and dissimilar physical characteristics; thus,the inclusive designed product can be used by variouse users and can be mass-manufactured.Therefore, the surveywas conducted with IASD and PASD, who are the potential users, to develop an inclusive design that can be used by various users with different ASD symptoms and preferences. One group consisted of individuals with ASD living in the U.S. and did not have an intellectual disability but did meet DSM-V or DSM-IV criteria for ASD. The second group of participants consisted of parents of IASD (PASD). Participants were asked to respond to questions by writing instead of recording their voicesin consideration of people with ASD who might be reluctant to express their opinions or talk with an unfamiliar person and who might prefer writing a way of controlling their phases when answering each question without pressure. For the survey 1 which investigated preferences, some participants were recruited through presentations made to social skills groups at the Medical Investigation of Neurodevelopmental Disorders Institute; others indicated interest in participating by contacting the Neurocognitive Development Laboratory. After the survey 1, in order to answer research question 3, a prototype was developed based on the preferred functions and design features and important design factors defined by the survey. For the survey 2, which evaluated the prototype, purposeful sampling was used. In order to maintain consistency with the survey 1, participants were recruited who met the same requirements used for the preference survey. The recruiting information was uploaded online and volunteers contacted us to participate. The prototype was shown while completing the survey. For both surveys, participants gave informed consent and completed a 30- to 60-minute survey.

3. 2. Measurement

The survey 1 included a total of 24 open- and closed-ended questions and the majority of questions were open-ended: two about demographic information (age and gender); three about ASD symptoms (age of diagnosis, prevalent ASD symptoms, and difficult challenges faced in daily life); 12 about important design factors, measured with a 5-point Likert scale (1=strongly disagree and 5=strongly agree); five about preferred WT for ASD (item types, functions, design attributes, expected use frequency/use situation, data notification); and two about further suggestions. Survey 2 asked the same questions about demographic information and the same three questions about ASD symptoms whether the prototype satisfied 12 important design factors and whether they liked the prototype according to the defined function and design attributes. Participants ranked their responseson a 5-point Likert scale (1=strongly disagree and 5=strongly agree). One additional question asked for further suggestions. The collected datawere analyzed with color-coding, major theme extraction, and descriptive analysis including percentage, mean, and standard deviation. A series of Welch's t-tests using IBM SPSS 24.0 were conducted to investigate whether there were significant differences between IASD and PASD. Welch's t-test was used to compare the unequal variances (Delbaere et al., 2007; Moder, 2010). Cronbach's alpha coefficient was measured to assess the internal consistency of multiple indicators and the acceptable level is above .70 (Peterson, 1994). The Cronbach's alpha reliability values of the qualitative data wereall above .90 in the surveys 1 and 2 .after cross-checking inconsistency with two researchers, and the values of the quantitative data for design factors wereall above .80 in both surveys.

4. Result and Discussions

4. 1. Sample Characteristics

4. 1. 1. Demographic backgrounds

Survey 1. A total of 31 individuals living in the U.S. participated. Fourteen had an ASD diagnosis (12 male, 2 female, age range=11-37 years, m=19.29, SD=8.48), with ages of diagnosis from 3 to 33. Seventeen were PASD, whose care receivers (12 male, 5 female, age range=7-21 years, m=11.88, SD=4.21) were diagnosed between the ages of 1.8 and 14. Survey 2.The participants in both surveys had similar distributions of gender, age of diagnosis, and mean age.A total of 54 people were participated in the survey 2. There were 15 IASD (11 male, 4 female, age range=19-38 years, m=22.87, SD=2.95), with ages of diagnosis from 4-35, and39 PASD whose care receivers (18 male, 11female, age range=3-39 years, m=12.31, SD=8.26) were diagnosed between the ages of 1 and 10.Understanding users with different backgrounds will provide designers with insights into common needs to help them develop inclusive wearable productsfor disabilities (Carroll & Kincade, 2007).

4. 1. 2. Prevalent symptoms

It is important to understand the common symptoms of disabilities in order to develop wearable products for people with disabilities (Carroll & Kincade, 2007). Common ASD symptoms were defined from the survey data and the symptoms of the participants were similar to the common symptoms as reported in the reviewed literature (Dominick et al., 2007; McCraty & Zayas, 2014). The prevalent ASD symptoms were similar in both surveys. The most common symptom was communication problems such as not understanding social cues and having difficulty sharing feelings and thoughts, having delayed speech, or screaming (survey 1: 59.4%, survey 2: 31.5%); sensory issues such as becoming hyper- or hypo-aroused by auditory and visual stimuli and being overwhelmed with physical stimulation such as brushing hair, washing, etc. (survey 1: 43.8%, survey 2: 27.8%); social problems such as being unable to make friends (survey 1: 34.4%, survey 2: 18.5%); being prone to anxiety and getting stressed easily (survey 1: 21.8%, survey 2: 11.1%); having difficulty maintaining eye contact (survey 1: 18.8%, survey 2: 9.3%); using self-stimulation such as rocking back and forth (survey 1: 6.3%, survey 2: 1.9); and seizure activity (survey 1-6.3%, survey 2-none).

4. 1. 3. Challenges in daily life

The most difficult challenges faced in daily life were closely related to the prevalent symptoms. The challenges were similar in both surveys; the most commonly reported challenges were misunderstanding and miscommunication, such as difficulty with understanding appropriate and inappropriate behaviors and rules (survey 1: 48.4%, survey 2: 35.2%); difficulty with executing tasks such as daily planning, keeping track of time, or executing multistep activities (survey 1: 45.2%, survey 2: 5.6%); difficulty with self-regulating emotions, anxiety, and stresses or becoming easily overwhelmed (survey 1: 35.5%; survey 2: 31.5%); or difficulty with dealing with people (survey 1: 32.3%, survey 2: 22.2). Other challenges were sleep issues (survey 1: 6.5%, survey 2: 4.6%) and handling living expenses (survey 1: 3.2%, survey 2: none).

4. 1. 4. WT use experiences

Among IASD and PASD, 20% (survey 1) and 42.5% (survey 2) had used WT types of aids for communication such as hearing aids and smartphones for their ASD symptoms. About 17% (survey 1) and 25% (survey 2) responded that they have used aids for physiological awareness and self-management such as sleep monitoring and fitness tracking. IASD reported using WT for aiding daily tasks and PASD reported using it to track and monitor their care receivers.

4. 2. Important Design Factors

Among the 12 WT design factors, 9 design factors had an average ranking of 4 or higher out of 5 (Table 2). When the mean and standard deviation for all participants was calculated, the most important design factor was comfort (m=4.56, SD=.64) followed by data accuracy and durability. The most important factors for IASD were durability, which was important for long-term use specially for children uses (Hartman, 2014). PASD considered comfort (m=4.78, SD=.43) the most important factor. Many IASD have sensory issues and comfort is important for these symptoms and also for long-term use (Dominick et al., 2007; Buenaflor & Kim, 2013). Data accuracy is important since it is for people with ASD symptoms; portability will make the WT easy to use constantly (Lukowicz, Kirstein, & Troster, 2004); and flexible material will allow long-term use with increased comfort (Gómez et al., 2008). According to the Welch's t-tests, there were no significant differences between the two groups on important design factors.

Table 2 Important design factors for WT for ASD

Analysis	Group	Mean *(SD)*	*Rank*	Mean *(SD)*	*Rank*	Developed prototype
Comfort	IASD	4.17 (.66)	4	4.56(.64)	1	Wear like a normal glove, made of soft fabrics
	Parents	4.78 (.43)	1			
Data accuracy	IASD	4.25 (.97)	2	4.52(.80)	2	Data triangulation using two different sensors (GSR and HR)
	Parents	4.67 (.59)	2			
Durability	IASD	4.33 (.91)	1	4.50(.81)	3	Circuits are sealed with a lining
	Parents	4.60 (.59)	3			
Portability	IASD	4.21 (.91)	3	4.44(.83)	4	Wear like a normal glove
	Parents	4.53 (.61)	4			
Flexible material	IASD	4.17 (.77)	4	4.42(.70)	5	Made of flexible fabrics and circuits
	Parents	4.47 (.61)	5			
Ease of use	IASD	3.99 (.88)	5	4.19(1.08)	6	Wearlike a normal glove
	Parents	4.44 (1.1)	6			
Safety	IASD	3.85 (1.35)	6	4.07 (1.27)	7	The lining is covered preventing the circuits contacting the skin
	Parents	4.28 (1.13)	9			
Unnoticeable design	IASD	3.63(.9)	9	4.02(1.02)	8	Regular glove, all circuits are hidden
	Parents	4.4 (.91)	7			
Lightweight	IASD	3.67 (1.06)	8	4 (1)	9	Lightweight fabrics and fabric–based lightweight circuit components
	Parents	4.33 (.77)	8			
Reasonable price	IASD	3.68 (1.13)	7	3.81(1.11)	10	Approximate sale price islower than $60–90 (after 2–3x margins),lower than about $150 average wearable price (Statista, 2014)
	Parents	3.85 (.96)	11			
Small size	IASD	2.94 (1)	10	3.50(1.14)	11	All circuit components are minimized
	Parents	3.87 (.96)	10			
Unique design	IASD	2.75 (1.42)	11	2.92(1.55)	12	Different to extant WT for ASD
	Parents	3.05 (1.43)	12			

Note: 1=strongly disagree to 5=strongly agree

4. 3. Preferences on functions and design attributes of WT for ASD

4. 3. 1. Item types

The most preferred item types of WT for IASD (60%) and PASD (77.8%) were accessories such as watches or bracelets followed by garments (IASD=6.7%; PASD=11.1%) (Table 3). More than 33% of PASD commented that the WT should not attract attention or distract their care receivers which is important for long-term use (Buenaflor & Kim, 2013; Pantelopoulos and Bourbakis, 2010).

4. 3. 2. Functions

IASD most preferred to use WT that could monitor body signals such as heartbeat and respiration (46.7%) (Table 3), which is related to difficulties with monitoring or awareness of their own emotional state (McCraty & Zayas, 2014). IASD wanted to alert them of physiological signals, such as signs that the user is stressed (26%), and this can be utilized with the monitored body signals (McCraty & Zayas, 2014). The others were devices such as earpieces for tuning out environmental stimuli (22.2%) which can be helpful for sensory processing problems such as hypersensitive (Autism Speaks, n.d.; Dominick et al., 2007). Other features they wanted included devices to notify when it is appropriate to eat (13.3%) for eating obsessive behaviors (Autism Speaks, n.d.), and devices with voice recognition (12.5%) for communication difficulties (Dominick et al., 2007).

The PASD preferred functions related to WT types of aids for awareness and management (Table 3). For example, a) tracking their care receivers' body signals to understand anxiety level or emotions (72.2%) to relieve mood and anxiety issues (Autism Speaks, n.d.; Dominick et al., 2007). According to the research results, one of the most common challenges IASD had was self-regulating emotions, anxiety, and stresses; b) one of the challenges IASD had in their daily lives was reminding users of the next step in multi-step tasks (44.4%) and executing tasks such as executing multistep activities; and c) monitoring activities or locations (22.2%). This topic may have been frequently mentioned because PASD worry about losing their care receivers.Other suggestions were sleep pattern monitoring (16.7%) to relieve sleep deficits, and this is one of the most common symptoms of ASD (Autism Speaks, n.d.; Dominick et al., 2007), and social connectivity (11.1%) for better human interactions (Autism Speaks, n.d.; Dominick et al., 2007). According to the results, both IASD and PASD most preferred monitoring body signals for understanding anxiety, emotions, and stress level.

4. 3. 3. Design attributes

About 47% of IASD and 44.4% of PASD preferred to have unnoticeable designs, important for long-term monitoring WT (Buenaflor & Kim, 2013; Pantelopoulos and Bourbakis, 2010) (Table 3). After that, 26% of IASD and 33% of PASD commented that they would prefer WT that is made of flexible materials that are critical to comfort and unobtrusive designs (Gómez et al., 2008). Both IASD (11.1%) and PASD (13.3%) wanted WT that is easy to put on and take off. IASD also preferred that WT be lightweight (6.7%) that can affect the comfort level for long-term use (Knight & Baber, 2005).

4. 3. 4. Expected use frequency/use situation

Many IASD (80%) and PASD (87%) responded that they would use WT every day, but some wanted to use it only at special occasions such as when IASD (13.4%) went somewhere stressful (6.7%) or in the gym (6.7%) (Table 3). Most IASD (86%) wanted to use WT in stressful situations such as social gatherings with new people or to prevent embarrassing situations by increasing their self-awareness. Interestingly, more than 88% of PASD also wanted WT that can monitor emotion or stress levels of IASD at stressful situations, because their care receivers' emotions and stress levels can be difficult to predict and their communication skills may be limited which is the common symptoms of IASD (McCraty & Zayas, 2014; Dominick et al., 2007).

4. 3. 5. Data notification

The majority of IASD (60%) and PASD (83.3%) preferred to receive the monitored data through smartphone apps due to their ease of downloads, ubiquity, and portability, which is the similar to the results of the previous research on WT for healthcare (Koo et al., 2016). Other IASD suggested notifications through software stored in the device itself (13.3%), while other PASD suggested notifications through webpages (16.7%) (Table 3).

4. 3. 6. Other important aspects

IASD wanted the WT to store information about medical conditions and addresses (20%) (Table 3). Some PASD suggested making the product individually customizable for accuracy (20%) or using WT for future research and therapy for ASD (11.1%). Other suggestions included making it waterproof, durable, and controllable by parents; and making data history accessible.

Table 3 User preferences, important design factors, and developed prototypes

Group	Preference	%	Developed prototype	
Item types				
IASD	Accessories	60	V	Accessory type
	Garments	6.7		
PASD	Accessories	77.8	V	Accessory type
	Garments	11.1		
Functions				
IASD	Aids for physiological awareness– monitoring body signals	46.7	V	Aids for awareness through body monitoring
	Aids for physiological awareness–alerting body and emotional changes	26	V	Alert the data to self– and caregivers
	Aids for calming and relieving–Turning out environmental stimuli	22.2		
	Aids for task management (e.g., notification for appropriate behaviors)	13.3		
PASD	Aids for physiological awareness –care receiver's body and emotions)	72.2	V	Aids for awareness through body monitoring and alert the data to self–and caregivers
	Aids for task management –reminding next task steps	44.4		
	Aids for task management – activities or locations	22.2		
	Aids for physiological awareness and task management – sleep patterns	16.7		
	Aids for communication –social connectivity	11.1		

Design				
IASD	Unnoticeable design	46.7	V	Neutral color (black), regular glove, all circuits are hidden
	Made of flexible materials	26	V	Made of flexible materials–fabrics and flexible circuits
	Easy to put on and take off	11.1	V	Made of stretchable materials (fabrics and soft rubber bands),
	Lightweight	6.7	V	Lightweight fabrics and circuit components
PASD	Unnoticeable design	44	V	Neutral color (black), regular glove, all circuits are hidden
	Made of flexible materials	33	V	Made of fabrics
	Easy to put on and take off	13.3	V	Made of stretchable materials (fabrics and soft rubber bands)
	Lightweight	6.7	V	Lightweight fabrics and flexible circuit components
Use frequency				
IASD	Everyday	80	V	An accessory typethat can be easily took off depends on users' decisions
	Only at special occasions	13.4	V	
PASD	Everyday	87	V	
Use situation				
IASD	Stressful situations	86	V	Aids for monitoring stresses and emotionalchanges
PASD	Stressful situations	88	V	
Data notification				
IASD	Receive data through smartphone apps	60	V	A smartphone app is showing the collected data to users
PASD	Through Webpages	83.3	V	
	Through Webpages	16.7		

Note: V=selected design attributes when developing the prototype

5. Prototype Development: AutiSense

5. 1. Function

A prototype called AutiSense was developed in this studybased on the survey results (Table 2 &3). The most preferred function of WT was to monitor body signals such as heartbeat and respiration to inform the wearer or caregivers about the wearer's emotional state, allowing increased self-awareness and self-adjustment. This function can be facilitated by monitoring the physiological changes from the autonomic nervous system and transmitting the data to a mobile platform for display. Thus, the prototype for this study measures galvanic skin response (GSR) with sensors to detect skin-conductance changes, measures heart rate (HR) with a pulse oximeter, and tracks HR variability to measure physiological parameters (Bertuleit, 1991). Skin conductance changes according to the activity in the sympathetic branch of the autonomic nervous system, and GSR detects skin conductance through sweat produced by the eccrine sweat glands that are densely located in the volar regions of the hand (Moore & Dua, 2004). HR and HR variability are parameters measured to acquire more precise feedback about emotions.

5. 2. Design

Based on the survey, the most preferred item type was accessories (Table 2 &3). IASD wanted to use the WT every day, but they only wanted to use it somewhere stressful or in a gym. Therefore, the prototype was developed as a wearable fabric accessory to allow the users to wear it every day or to easily take off if they decided to wear it only for special occasions. Among the body zones where sweat glands are densely located, fingers are the best area to collect GSR (Moore & Dua, 2004). Initially, prototypes of wrist band and ring-type sensors were fabricated; however, these prototypes were not large enough to measure skin conductance, and their small size made them unstable and easily affected by body movement signals. Thus, a thin and well-fitted glove was developed to hold the main components of the device and make the sensors contact skin continuously, an important consideration for measuring the signals. The glove's fit is designed such that each of the sensors has enough compression so as not to move around the fingertip, yet the glove is not so snug as to occlude circulation. To meet the expected design aspects from the survey, black colors are used to make the design unnoticeable; stretchable fabrics and conductive fabrics are used to replace hard wires and minimize stiff electronic devices so that the device is comfortable and lightweight; thin cotton fabrics are used to make the device flexible; and stretchable and rib weaves are used at the wrist to make the glove easy to don and doff. Conductive thread (Ag based, 20-30 Ohms) is sewn into the glove to form electrical contacts between the sensors, and microcontroller and conductive fabrics are used for GSR sensors (Ag based, 0.02-5 Ohms). The GSR sensor consists of two conductive pads which contact the palmar side of the hand at the distal phalanges by utilizing flexible conductive pathways with conductive threads.

Figure 1 The glove "AutiSense"

5. 3. Working Mechanism

A voltage under 1.5V is run across conductive pads and the resistance is measured using a Wheatstone bridge circuit comprising a 1MOhm resistor and two 10kOhm resistors, including a differential amplifier and buffer stages to discern changes in skin resistance and analyze the changes through an embedded board containing signal analysis circuitry and a microchip. The GSR function was explored through experiments using a pinprick that elicited a sympathetic response by the sweat glands, resulting in increased secretion and decreased skin resistance on the fingertip (Figure 2). These changes occur because sweat contains water and electrolytes. If a person experiences stress, sweat secretion increases, which in turn increases electrical conductivity and ultimately lowers the skin's electrical resistance agna, 2003).

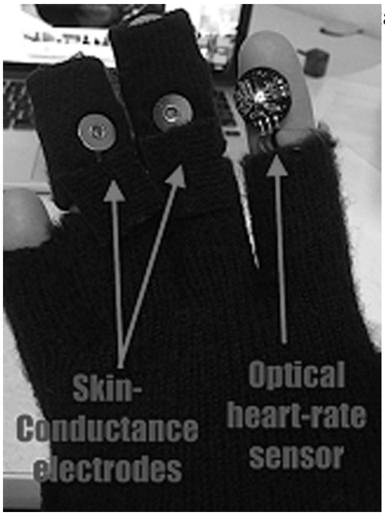

Figure 2 Sensor configuration tests before integrating with gloves

To measure HR and HRV, the glove uses a pulse oximeter to obtain a photo plethysmograph to detect the pulse by shining a green light-emitting diode (LED). A sensor on the finger analyzes the reflected light intensity pattern through a photodetector and other signal analysis circuitry (Tremper, 1989). This intensity pattern is then analyzed by a microchip to measure HR and HRV. The LED, photodetector, and other circuit elements are incorporated in an embedded board (Figure 3).

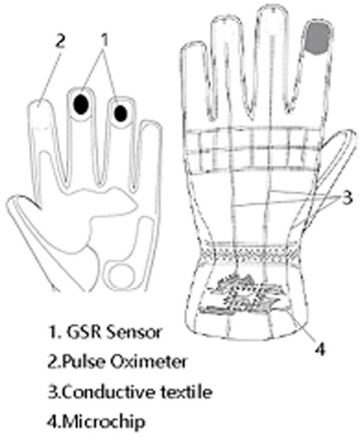

Figure 3 Component configurations of the gloves

5. 4. Data Notification

In the interview results, both IASD and PASD most preferred to receive data through smartphone apps. The most preferred function of the WT for ASD was to monitor data and show the data users to users to inform them about their emotional states for better self-awareness and self-adjustment. Hence, the prototype was developed to wirelessly transmit the collected sensing data to a smartphone app for display and analysis. A smartphone app for the prototype was also developed. Data is collected from the two sensors through analog-to-digital converters (ADCs) within the control circuit, in which ADCs are coupled to a microcontroller as a processor. A BlendMicro® board is used with Arduino® for programming for the glove circuit. The microcontroller is compatible with Bluetooth 4.0 (Bluetooth Low Energy, BLE; nRF8001 integrated circuit by Nordic Semiconductors®). The developed app is called AutismApp and the code uses the Bluetooth module on the Apple iPhone running iOS to search for the embedded microcontroller described above. On the AutismApp, the received information is graphed on a line plot for visual interpretation by the user. Two external libraries were used: a) CorePlot, licensed by the BSD License, and b) a Bluetooth LE example from Scott Gruby released by the MIT License.

5. 5. Prototype Evaluation

When participants were asked how much they liked (1=strongly disagree to 5= strongly agree) each design aspect according to the defined preferred functions and design attributes, the mean average of the results were all above 3 for both groups (Table 4). Thus, overall, the participants liked the prototype in the aspects of the item type, functions, design attributes, use frequency/ use situation, data notification methods, and the overall designs and functions. The most liked aspect was the lightweight of the glove, followed by the data notification method, and the least liked aspect was the item type. Some participants suggested that the glove would be not appropriate in warm weather and some geographic areas and could easily be removed by the IASD. Thus, participants suggested making the fingertips open or adding a string to hold the left and the right gloves. A series of Welch's t-tests were conducted to investigate whether there were significant differences between IASD and PASD.IASD and PASD showed differences in the extent to which they liked the unnoticeable design, data notification method of using a smartphone app, and the overall functions ($p<.05$). IASD were more likely than PASD to like unnoticeable design ($t=-.659$) and the data notification of the prototype ($t=-.072$). PASD liked the overall function of the design more than IASD ($t=2.355$) did (Table 4).

Table 4 Evaluations on functions and design attributes of theprototype

Evaluation		IASD	PASD	All	Rank	t-value
Ilike the glove's ( ).		Mean (SD)	Mean (SD)	Mean (SD)		
Item type	Accessory-glove	3.27 (1.22)	3.21 (1.26)	3.22 (1.24)	12	
Functions	Aids for awareness through body monitoring and alert the data to self- and care givers	3.6 (1.06)	3.71 (1.09)	3.68 (1.07)	6	
Design	Unnoticeable design- neutral color (black)	3.80 (.86)	3.49 (1.19)	3.57 (1.11)	9	
	Unnoticeable design-regular glove, all circuits are hidden	3.33 (.90)	3.54 (1.29)	3.48 (1.19)	10	-.659*
	Made of flexible materials-fabrics and flexible circuits	3.4 (.91)	3.74 (1.09)	3.65 (1.05)	7	
	Easy to put on and take off- made of stretchable materials (stretchable fabrics and soft rubber bands)	3.80 (.77)	3.85 (1.14)	3.83 (1.04)	3	
	Lightweight- lightweight fabrics and circuit components	3.87 (1.13)	3.92 (1.01)	3.91 (1.03)	1	

Use frequency	Everyday use or for special occasions– an accessory typethat can be easily took off depends on users' decisions	3.47 (.99)	3.64 (1.18)	3.59 (1.12)	8	
Use situation	Stressful situation–aids for monitoring stresses and emotional changes	3.8 (.77)	3.82 (1.25)	3.81 (1.13)	4	
Data notification	Smartphone app–shows the collected data	4 (.85)	3.79 (1.17)	3.85 (1.09)	2	–.072*
Overall	Overall designs	3.93 (.96)	3.15 (1.37)	3.37 (1.31)	11	
	Overall functions	4.07 (.96)	3.54 (1.14)	3.69 (1.11)	5	2.355*

Note: 1=strongly disagree to 5=strongly agree; *〈.05

For both IASD and PASD, the results of the evaluation of the prototype according to the 12 defined important design factors all showed above 3 on mean average(Table 5). The design factor that most satisfied participants was that the WT was small and the glove was safe to use. The design factor that most satisfied participants was that the WT was small and the glove was safe to use. The design factor that least satisfied users was the lack of unique design. The glove was designed to be unnoticeable designs. Thus, the glove design could be varied but would still look like a regular glove or make into another item type that is more unnoticeable. Some participants suggested making the glove pink for female users or other fun colors for kids (3.7%). Also, considering that among the 12 design factors, unnoticeable design was not one of the ones that most satisfied participants, designers would need to make the glove with a more unique design but still unnoticeable design. One way to achieve this goal would be to make other accessory types or garments, which were the second most preferred item type, instead of gloves. Some participants suggested making a T-shirt type or skin-colored accessories (1.85% for each). According to the Welch's t-tests, IASD and PASD showed different levels of satisfaction with the prototype. However, there was no significant difference in satisfactions with other design factors(Table 5).

Table 5 Evaluations on the design factors of the prototype

Evaluation	IASD	PASD	All	Rank
The AutiSense–prototype satisfies ( ).	Mean (SD)	Mean (SD)	Mean (SD)	
Comfort	3.73(.88)	3.49 (1)	3.56 (.96)	8
Data accuracy	3.4 (.63)	3.62 (1.02)	3.56 (.92)	7
Durability	3.67 (.98)	3.47 (1.08)	3.53 (1.05)	9
Portability	3.53 (.92)	3.82 (1.23)	3.74 (1.15)	5
Flexible material	3.73 (1.16)	3.85 (1.16)	3.81 (1.15)	3
Ease of use	3.53 (.74)	3.77 (1.11)	3.7 (1.02)	6
Safety	3.73 (.70)	3.85 (1.11)	3.81 (1.01)	2
Unnoticeable design	3.67 (.82)	3.46 (1.39)	3.52 (1.26)	10
Lightweight	3.73 (.88)	3.77 (1.16)	3.76 (1.08)	4
Reasonable price	3.8 (.77)	3.23 (1.16)	3.39 (1.09)	11
Small size	3.8 (.94)	3.85 (1.04)	3.83 (1.00)	1
Unique design	3.6 (.99)	3.26 (1.25)	3.35 (1.18)	12

Note: 1=strongly disagree to 5=strongly agree; *〈.05

6. Conclusion

This research identified potential consumers' preferred design features for WT for ASD and developed a WT design. This study investigated the preferences of IASD and PASD for WT for ASD, focusing on what functions and designs makes a WT item appealing, and developed a WT prototype along with a smartphone app. WT has the potential to decrease care expenses, assist in treatment, and increase quality of life and wellness for IASD and their family members. However, little previous research has focused on understanding what IASD and their families need and want in WT for ASD. According to the results, designers could develop WT to relieve sensory issues, communication problems, and self-regulation issues, which are common symptoms of ASD (Dominick et al., 2007; McCraty & Zayas, 2014).

Regarding the first research question, designers and product developers also need to meet users' needs for comfort, data accuracy, durability, and portability, all of which were scored as important factors by both IASD and PASD. Comfort, durability, and portability, and flexibility are important for long-term use (Buenaflor & Kim, 2013; Gómez et al., 2008; Hartman, 2014; Knight & Baber, 2005; Lukowicz, Kirstein, & Troster, 2004). Data accuracy would make WT more reliable and acceptable for real applications (Lymberis & Gatzoulis, 2006).

In terms of the second research question, the most preferred function of WT for awareness such as monitoring body signals of hearbeat and respiration to check stress level and emotion. This could enable IASD to improve their self-regulation and PASD to understand and to react appropriately to their care receivers. The literature shows that technology for measuring heartbeat variability can give insight into emotional changes, but not many products for IASD use this technology. The existing technology could be further modified for IASD by calibrating collected data and considering IASD's symptoms and design needs. Other design features that participants wanted included devices that send messages to smartphones to alert that the user is stressed. Designers and product developers are encouraged to make accessories such as watches, bracelets, earpieces, or socks. The designs need to be unnoticeable, made of flexible materials, and could communicate with compatible smartphone apps.

For the third research question, a prototype was developed based on the research results and evaluated. Overall, the prototypeachieved the identified functions and design attributes and satisfied the important design factors. However, several aspects could be improved. For example, future versions could be a different type of item, such as an accessory or a garment. The design could be more unnoticeable but also be more unique. The glove type could also be developed into diverse items after investigating the best areas to monitor skin conductance and HR or use other sensors to monitor physiological changes.IASD were more likely than PASD to like the smartphone app. Hence, different modes other than the smartphone app could be set up for better notifications and information displays for PASD.

There is no previous research investigated preferences or defined important design factors on WT for ASD. The results can guide designers when developing WT for ASD and ultimately benefitIASD and their families. Considering the privacy and accessibility of IASD and their parents, the number participating in this study is acceptable (Sandelowski, 1995). The most commonly preferred item types for the WT were accessory or garment types; this preference could have influenced the other preferred design attributes and design factors. Thus, it could be interesting to investigate whether there are differences to consider when developing different item types. Because of the wide age range among participants, there were a limited number of participants in each age group. Thus, it would be worthwhile to conduct surveys among large populations to investigate whether there are differences among groups with different demographic backgrounds. In addition, it would be meaningful to hear expert opinions, besides users' opinions, and to conduct interviews and observations with both experts and users.These research efforts can be extended to people suffering from other developmental, neurological, or sensory disorders such as ADHD and dementia.

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