One Size Does Not Fit All: A Smarter Way to Develop Computer Assisted Interventions for Children with ASD

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Abstract

The number of individuals seeking treatment for autism spectrum disorders (ASD) is increasing quickly and families often have difficulty accessing effective therapy. A number of computer assisted interventions (CAI) have been developed in an attempt to address these needs. However, most development of CAI has taken place in the absence of an understanding of how variability in ASD behavioral phenotypes may affect CAI effectiveness. The current effort describes the first step towards developing a framework to understand how behavioral phenotypes among those diagnosed with ASD can inform the design of CAI. Specifically, we propose a four-step methodology to better inform the design and development of such CAI. Generally, these steps involve by (1) identifying a need where CAI is appropriate, (2) identifying a technology or set of technologies that are relevant for that population, (3) identifying an appropriate population that stands to benefit from our CAI, and (4) identifying specific content to be included in our CAI. We also describe the results of an effort applying this proposed methodology for the development of our CAI.

Keywords: *autism spectrum disorder (ASD), computer assisted interventions (CAI), children, orientation games, motor skills, attention, serious games*

1. Introduction

1.1. Background

Currently, no treatment method completely ameliorates the symptoms of autism spectrum disorder (ASD) and no specific treatment has emerged as the established standard of care for all children with ASD. However, the most well researched programs demonstrating effectiveness are based on the principles of applied behavior analysis [1] [2] [3]. Implementation of evidence-based interventions can potentially improve outcomes and decrease the long-term cost of caring for these children [4] [5]. These studies estimate the annual cost of caring for individuals with ASD are $3.2 million per capita, and the savings achieved through early intervention are approximately $280,000 by age 22, illustrating that quality early intervention efforts are not misplaced. However, evidence based practices for autism have not been efficiently translated into community settings, and are often difficult to access [6][7].

Therapy for ASD is intensive and costly and most families cannot afford to provide the recommended 25 hours of intervention per week for their children. Additionally, families in low-resource and rural areas may have difficulty finding qualified providers. Even for those families that have access the cost of treatment increases for families as their children age due to decreases in government funding and often increases in medical and/or behavioral issues due to the policies that govern coverage of certain services [8] [9] [10]. The confluence of these factors demonstrates a need for methods that can lower cost and increase intervention accessibility and intensity. Coincident to this need, advances in multimedia technologies make it possible to deliver very enriched and immersive virtual experiences. Similar technologies may be appropriate for improving access to ASD intervention.

1.2 Technology and ASD

The need for cost effective and accessible treatment, as well as recent advances in technology, has spurred an increase in the development of computer assistive interventions (CAI) for this population. CAI has been developed for various cognitive therapies including treatment of depression [11][12][13]. Some of the core features of CAI such as predictability, consistency and lack of social demands make it particularly appealing to those with ASD [14]. CAI users are able to work at their own pace, and the automation means that there is no cost associated with repeated exercises, making intervention more accessible. Current research suggests that children with ASD experience computer interaction as 'safe' [15]. That is, computer systems represent a controlled environment with minimum or no distractions, which is crucial in the educational process for those with ASD.

Recent data directly examining the potential benefit of a computer assisted intervention for those with ASD, called TeachTown, found an increase in motivation to participate in the intervention and increased social interactions relative to a usual care baseline [16][17]. In another example, [18] found that the use of an augmented reality system (AR) significantly advanced the pretend play abilities of two children with ASD. Further, Lányi and Tilinger [19] demonstrated that utilizing emotionally expressive avatars can act as therapeutic technology for people with ASD.

Despite early evidence of its utility, a recent review examining the use of CAI for children with ASD [20]. found that most CAI solutions have not been validated as clinically effective tools. The studies conducted by [16][17] are the exception. There is even less evidence regarding how to develop and design CAI. Understanding the needs of the user along with the benefits and limitations of a given technology should help guide the design and development of more effective CAI.

1.3 Need for Personalized CAI for use with ASD Therapy

One important weakness of the current literature regarding CAI for autism is a lack of understanding of how the heterogeneity in behavioral phenotypes among those diagnosed with ASD affects efficacy of a given CAI. Unfortunately, there are no well-defined methodologies for developing CAI solutions for children despite reports of efforts to incorporate participatory design framework in developing CAI for children with ASD [22]. Thus far, the results from these efforts are too general to offer meaningful guidance. Some authors have provided suggestions for using technology with ASD populations [22] [23]. Although these reports acknowledge the inherent variability with regard to the behavioral phenotypes of children diagnosed with ASD, they do not offer any predictability for whom guidelines might actually work. At this time researchers acknowledge the general lack of guidelines for developing CAI for this population [24].

There is some evidence demonstrating that categorical estimates of severity of ASD predict response to behavioral treatment [25]. It seems useful, then, to develop a methodology which, in turn, informs and constrains development of new technologies in order to maximize clinical relevance and effectiveness. We expect that the heterogeneity that exists among the population of children with ASD makes it unlikely that the development of CAI for the Kinect will provide benefit for all children with ASD uniformly. In fact, current therapeutic delivery requires some level of trial and error on the part of the therapist to understand which therapeutic approach is most effective for a particular individual. Ultimately, our aim, as is the aim of the ASD community at large, is to develop a way to stratify the population of children with ASD in order develop CAI in a more intelligent and effective way. Developing CAI in the absence of a fundamental understanding of the different needs and characteristics of groups of individuals diagnosed with ASD makes it unlikely that a given CAI will be successful. To that end, we sought to develop an agile methodology to help inform our development of CAI to deliver automated social skills therapy for children diagnosed with ASD.

The goal of the present manuscript is to present a methodology used to develop our CAI along with early results employing this methodology. It is important to acknowledge that any initial attempt to develop any such methodology will, inevitably, be limited and incomplete. Minimally, more data will always provide a measure of robustness for the results observed using the methodology. The results presented in the present manuscript are merely illustrative and provide a practical implementation of our stated methodology. Briefly stated, our methodology is meant to increase the likelihood of developing effective CAI by (1) identifying a need where CAI is appropriate, (2) identifying a technology or set of technologies that are relevant for that population, (3) identifying an appropriate population that stands to benefit from our CAI, and (4) identifying specific content to be included in our CAI.. Obviously, the development of any CAI will include all of these activities. The unique benefit to our approach, one that we feel is critical, is the ability to capture more objective and more reliable data to help inform steps (1) – (4). Having more objective and reliable data is integral to the success of any CAI development, particularly those for which the behavioral traits and goals are relatively heterogenous, as is the case with children diagnosed with ASD. Although the initial results of our methodology demonstrated effectiveness with respect to the design and developing of our CAI for children diagnosed with ASD, the general principles outlined in the methodology make it extensible to other therapeutic domains.

2. Methodology

As already mentioned, the four primary goals of developing CAI include (1) identifying a need where CAI is appropriate, (2) identifying a particular technology or set of technologies appropriate to address this need, (3) identifying the appropriate population that stands to benefit from our CAI, and (4) identifying specific content to be included in our CAI.

Step :1 Identifying a need for CAI: As stated in the Introduction, we have already identified a critical need for greater access and more cost efficient therapy delivery mechanism for children diagnosed with ASD, social skills in particular. The second step in the process, identifying candidate technologies for developing CAI, is described in the following section.

Step 2: Identifying a Technology or Set of Technologies: There is a growing body of evidence demonstrating the usefulness of CAI as a way to increase access to and reduce costs for therapy. Obviously, though, different technologies confer different advantages as well as contain disadvantages. For example, the primary advantages conferred by developing CAI for desktop computers include the computing power along with a large visual space. However, unlike tablets and smartphones devices, they are limited in their mobility. Like desktop computers, most current gaming systems have relatively high computing power and a large visual space with the added advantage of being an established medium for engagement. One gaming system in particular that possesses a unique advantage for developing CAI is the Microsoft Xbox Kinect gaming system. The Kinect motion-sensing camera works with the Xbox gaming platform and is used in conjunction with the Xbox gaming software so that movements specific to the user(s) is represented real-time in the software, providing a naturalistic and often more engaging experience. Given the relative ease-of-use and comparative cost-friendliness of this platform, it seems worth investigating the platform's potential for delivering clinically effective therapy for children diagnosed with ASD. The interactive nature of the Kinect platform may have potential for implementing social skills intervention via collaborative virtual worlds, something that has been shown to provide greater benefit than seemingly more isolating mobile technologies such as phones and tablets [26] [15]. In addition, there may be a benefit to using natural interfaces to interact with the games. Although little research evidence exists that examining natural interfaces as tools for engagement, there is evidence suggesting that engaging whole body movements into video game play could provide, at a minimum, a cognitive benefit. Given there is, at best, a weak theoretical basis for choosing to develop CAI for the Kinect system, we felt it was necessary to gather sufficient data that could inform whether or not the Kinect is usable for children with ASD in the context of therapy delivery. Step 3: Identifying Appropriate Users: It makes intuitive sense that a given CAI is unlikely to work equally well for all users. Given the heterogeneity of behavioral symptoms observed in children with ASD, this is especially true. Thus, it is critical data is gathered to help better define the characteristics, behavioral and otherwise, that directly influence the effectiveness of a given CAI. For example, one may need a certain level of cognitive functioning to successfully navigate the system or simply tall enough to be 'seen' by the camera. As mentioned in the prior section, although many anecdotal reports of the Kinect system applied for ASD therapy exist, evidence supporting the efficacy and usability of the application of the Kinect platform for ASD therapy is scarce. Prior research [27] provides only indirect evidence of the usability of the Kinect-based platform with children with ASD. Essentially the authors found that of the five children diagnosed with ASD that were evaluated, three were able to successfully interact with the Kinect-based system while two were unsuccessful. However, limited information was available regarding child characteristics that predicted success. Part of our methodology involves a way to collect data that can help designate a set of necessary and sufficient characteristics.

Step 4: Identifying Relevant Content: Once these characteristics for target users have been identified, we can then more intelligently decide on particular content to develop. Defining relevant content for target users is obviously critical to the developing effective CAI. But defining content can only happen once relevant demographic characteristics have been well-defined. Generally speaking, the proposed methodology involves informally scoring behavioral interactions from a group of individuals using the Kinect-based CAI. This scoring allows us to better understand which individuals are appropriate for the Kinect-based CAI and which are not and, importantly, identify behavioral characteristics that allow us to define users that will be likely to benefit from the CAI. Once we establish who these individuals are and their associated behavioral traits, we can develop content targeted specifically for these individuals based on their particular behavioral phenotype and current therapy plans ultimately making the CAI more relevant and effective. It is important to remember that our methodology represents the first formal attempt at developing a guide to develop more effective CAI. While we provide important results that help validate our methodology, the methodology should be updated to incorporate a more rigorous way to collect and segment relevant behavioral characteristics. Minimally this would require more data collection. While informing our methodology with more data is a long-term ambition, the methodology presented here does provide a necessary and useful first step.

2.1 Subject Selection

Participants included 18 children with ASD ranging in age from 3 - 13 years. Inclusion criteria included (1) a diagnosis of an autism spectrum disorder (Autism, Asperger's disorder, or PDD-NOS) as determined by DSM-IV-R or DSM-5 criteria, and confirmed through record review; (2) being at least 48 inches tall to ensure adequate tracking by the Kinect system; (3) ability to follow one-step directions; and (4) a home environment that allowed set up and use of the Kinect system (presence of a television that could support 1080p HD video and sufficient space in front of the television to allow the child to move freely). Exclusion criteria included a presence of physical handicap that would prohibit use of the Kinect system and/or serious challenging behaviors that would prohibit the use of the Kinect. We did not provide any criteria related to overall functioning, behavior or skills of the child except the ability to follow simple directions, to better understand how heterogeneity in the behavioral phenotypes may affect their ability to engage and successfully interact with the Kinect system.

2.2 Setting and Materials

All sessions took place in participants' homes. The Kinect-based system was provided by the research team and consisted of a Microsoft Kinect camera and a laptop running Windows 7/8 with at least an Intel dual core processor 2.0 GHz. The television was provided by the families and supported 1920 x 1080 resolution (see Figure 1).

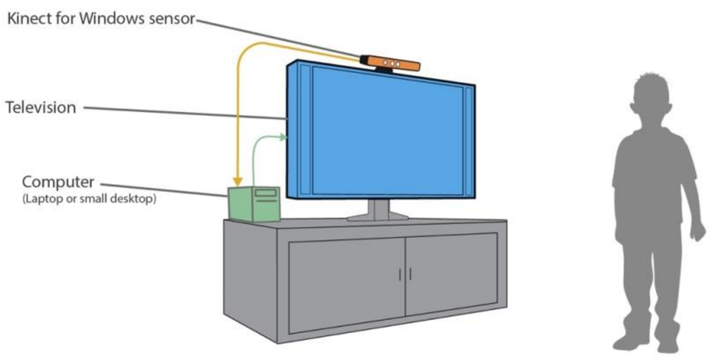

Figure 1. Schematic of the System Hardware.

2.3 Procedures

Recruitment and consent: Participants were recruited through local service agencies, parent organizations, and public awareness events. If a parent demonstrated interest, a phone screening was conducted to establish inclusion criteria and if the child met criteria an appointment was made for an observational session in the home where consent was attained prior to the start of the study.

Staffing: For each session, two research team members participated, one to video record the session and the other to work with the child. The research team was responsible for setting-up the Kinect system. Set-up consisted of (1) connecting laptop to TV (via HDMI); (2) Connecting Kinect camera to laptop using the Kinect USB adaptor; (3) Connecting the Kinect USB adaptor to an electrical source (outlet); (4) Booting the laptop and launching the application. A trained member of the research team with a background in ABA was present at each session. Prompts were provided to attend to the game and remain in the playing area if needed. All sessions were video recorded and were collected for later behavioral coding by trained coders.

Kinect orientation session: Each child participated in an orientation to the Kinect software to increase familiarity with the Kinect platform. Orientation games designed to be simple and fun for the child were presented that specifically taught the child how to maneuver within the Kinect system. Orientation games were custom developed designed by the team at WHI and meant to address several target behaviors with the idea that their presence is critical in order for an individual to receive effective therapy via a Kinect-based CAI. They are: (1) gesture navigation, (2) cause-and-effect relationships, and (3) divided attention. Three games were used. The first was a virtualized version of a 'whack-a-mole' game where children had to attend and react to spatially distinct parts of the screen. A second game testing motor skills and attention was a variation of 'Fruit Ninja' game, where children had to attend to several or more dynamic objects on the screen and quickly and accurately respond with motor movements to each one. Finally, a game where children had to respond to instructions given with both audio and with text and required them to guess among a set of objects tested their ability to attend, respond according to instruction, and comprehend feedback. All three games tested gesture navigation, which in this instance is the successful use of the Kinect cursor using a 'waving' motion of the hands to navigate the software. Likewise, a child was considered to successful attain cause-and-effect relationships if the child understood that his/her motions were represented on the screen and directly affected what happened in the software. This was also present in each game. Divided attention was assessed when individuals were forced to dynamically orient their spatial attention on the screen via the custom software game, again, present in each game. Children participated in at least one and up to two orientation sessions. Once the child performed sufficiently in all aspects of the orientation session they moved to the next session.

Each child participated in one additional session in which he or she played with an application that assessed behaviors specific to the ability to use the Kinect platform for therapeutic purposes. This application focused on teaching receptive language vocabulary in a discrete trial-like format, where the participants were given a command or asked a question and were required to use specific gestures to choose the correct answer from a field of three. Various levels of within-stimulus prompting were used within the game. Prompts were rapidly faded depending on accuracy of responding. Participants were required to accurately manipulate the Kinect cursor to choose a reinforcer to earn by completing up to three trials correctly. Reinforcers consisted of games that required gross motor movements to achieve simple tasks or short videos that included cartoons and other popular children's shows.

Assessments: The first 10 minutes of the video recording from each child's orientation session was coded by trained members of the research team. If the clip was less than 10 minutes, the entire clip was coded.

Coding: Coding measured the occurrence/non-occurrence of behaviors pertaining to the child's interaction with the Kinect within a 30 second interval. The 18 videos were coded by 3 behavior specialists. The child behavior codes included the following (behaviors were not coded for periods of time the child was off camera):

a) <u>On task behavior:</u> Captured the child's ability to participate in the designated activity/play. The child was considered to be on task if he/she was playing the game or attending to a video reinforcer appropriately, following instructions given by either the Kinect system or any adults in the room.
b) <u>Neutral comment</u>: Included factually based comments that did not reveal any emotion. This included any comments or questions that did not relate to the Kinect or game play, acknowledgements (including sounds such as 'hmm' or 'oh'), or objective comments (e.g., "That button says home").

c) Positive comment: Vocalizations directly related to Kinect interactivity that indicated the child was happy or enjoyed what he/she was doing, e.g., "This is fun," "I like that thing," "This is cool," etc.
d) Negative comment: Vocalizations directly related to Kinect interactivity that indicated the child was unhappy or dissatisfied with the game/what he/she was being asked to do (e.g., "This is stupid," or "Can I be done now?")
e) Social referencing: Nonverbal means used to initiate social interaction with others, including glancing at others in order to "check in," touching, or patting others. This item was only coded when the person the child was referencing was on camera.
f) Positive affect: Clear non-verbal indications of pleasure, such as clapping or smiling.
g) Negative affect: Clear non-verbal indications of displeasure such as foot stomping or frowning.
h) Inappropriate Behaviors: Any contextually inappropriate behavior, including avoidant behaviors. Any self-stimulatory behavior (i.e., flapping, prolonged visual inspection of parts of objects, or repetitive interactions with objects) lasting longer than 3 seconds or interfering with the child's ability to engage in the activity.
i) Inappropriate Vocalizations: Any contextually inappropriate vocalizations, including screaming, crying, and vocal stimulatory behavior (e.g., continuously repetitive language or scripted language).
j) Functional Kinect Use: Kinect use during the interval was coded as one of the following:
    1. Inattentive: Child not attending to the Kinect or his/her back was to the screen.
    2. Looking: Child was appropriately attending without moving parts of his/her body to control the Kinect.
    3. Moving: Attending to the Kinect with relevant and appropriate movement.
    4. No Opportunity: Kinect was between tasks/games for the entire interval or was not set-up.

Trained research staff coded the videos independently. Coding "keys" for each video were developed by consensus by discussing discrepancies between the coders for each video. Inter-coder reliability against the consensus key was assessed for each individual coder. Overall agreement was 97% across behaviors with a range of 80-99%.

Group development: Our approach to uncovering groups of children was much less formal than other, prior attempts at segmenting behavioral phenotypes of individuals with ASD [28] [29]. Given our goal of simply wanting to understand if there is a relatively coarse way to subdivide children with ASD into more meaningful groups based on their behavioral interactions with the Kinect-based CAI coupled with our small but meaningful data set, we felt that more formal attempts at segmentation were inappropriate and unnecessarily complex. Our method simply ranked ordered individuals based on a behavior we felt was indicative of whether or not a particular child would be able to successfully use the Kinect-based CAI to receive behavioral therapy. Based on this ranking we could observe if there was a tendency

Specifically, we assumed that the level of engagement, measured by the various levels of 'Kinect Use' (Inattentive, Looking, Moving, or No Opportunity), could be examined as a way to gauge how successful individuals were at using the Kinect system. Our grouping relied on coding of behavioral data based on behaviors likely to affect use of the Kinect system developed and internally agreed upon, including members of our development team along with trained BCBA licensed therapists. After ranking these individuals, our team assessed whether or not children grouped together based on this behavior. Finally, after separating these individuals into groups we identified the groups that were unable to successfully interact with the Kinect-based CAI, making it would be prohibitive to receive automated, behavioral therapy.

3. Results

3.1 Behavioral Coding

Tables 1-4 provide the results of the behavioral coding effort for each participant. Specifically, it indicates the percent of times an individual participant engaged in a given behavior relative to the number of opportunities they had to engage in the behavior is displayed (see Methods for more detail on coding). Figure 2 provides a scatterplot matrix of individual behaviors. Each plot contains individual data for a given behavior as compared to their Moving Behaviors for reference. Looking, Inattentive, and No Opportunity behaviors were not included in the scatterplot since these were mutually exclusive categories with the Moving Behavior category.

Table 1. Coded behaviors associated with each Group by participant. Groups were created according to the first column - the percent of time spent engaged in Moving Behaviors. The numbers associated with each column represent percentage of time spent engaged in the respective Kinect behaviors.

	Kinect - M	**Kinect - I**	**Kinect – L**	**Kinect – N/O**
Group 1 - High Moving Behavior				
Participant 8 Male, 12 yo	100	0	0	0
Participant 5 Female, 6yo	100	0	0	0
Participant 4 Male, 10 yo	100	0	0	0
Participant 2 Female, 8 yo	100	0	0	0
Participant 17 Male, 8 yo	95	0	5	0
Participant 11 Male, 7 yo	90	0	10	0
Participant 4 Male, 10 yo	80	0	0	20
Participant 3 Male, 10 yo	77	11	0	11
Participant 15 Female, 10 yo	75	25	0	0
Group 2 -Medium Moving Behavior				
Participant 13 Male, 9 yo	70	0	10	20
Participant 14 Male, 12 yo	65	5	20	10
Participant 7 Female, 6 yo	55	0	35	10
Participant 1 Male, 11 yo	50	0	5	45
Participant 9 Male, 7 yo	44	0	0	55
Group 3 - Low Moving Behavior				

Participant 6 Female, 3 yo	36	14	50	0
Participant 10 Male, 13 yo	20	0	60	20
Participant 18 Male, 12 yo	10	65	25	0
Participant 16 Male, 7 yo	5	35	15	45

Table 2. Coded behaviors associated with each Group by participant. Groups were created according to the first column - the percent of time spent engaged in Moving Behaviors. The numbers associated with each column represent percentage of time spent engaged in the respective social communication.

	Neg Comment	**Pos Comment**	**Neu Comment**	**Social Ref**
Group 1 - High Moving Behavior				
Participant 8 Male, 12 yo	0	0	0	0
Participant 5 Female, 6yo	53	73	67	7
Participant 4 Male, 10 yo	43	29	86	0
Participant 2 Female, 8 yo	20	15	15	10
Participant 17 Male, 8 yo	5	45	30	15
Participant 11 Male, 7 yo	5	0	50	0
Participant 4 Male, 10 yo	30	10	50	0
Participant 3 Male, 10 yo	22	22	44	11
Participant 15 Female, 10 yo	0	0	10	0
Group 2 -Medium Moving Behavior				
Participant 13 Male, 9 yo	0	0	20	35
Participant 14 Male, 12 yo	0	0	0	55
Participant 7 Female, 6 yo	30	5	55	25
Participant 1 Male, 11 yo	5	15	45	20
Participant 9 Male, 7 yo	0	0	44	0
Group 3 - Low Moving Behavior				
Participant 6 Female, 3 yo	0	0	14	43

Participant 10 Male, 13 yo	5	10	20	0
Participant 18 Male, 12 yo	0	0	0	75
Participant 16 Male, 7 yo	35	5	25	15

Table 3. Coded behaviors associated with each Group by participant. Groups were created according to the first column - the percent of time spent engaged in Moving Behaviors. The numbers associated with each column represent percentage of time spent engaged in the respective Appropirate and Inapprpriate behaviors.

	Inapp Behav	**Inapp Vocal**	**On Task**
Group 1 - High Moving Behavior			
Participant 8 Male, 12 yo	0	0	100
Participant 5 Female, 6yo	0	7	100
Participant 4 Male, 10 yo	14	0	100
Participant 2 Female, 8 yo	55	20	100
Participant 17 Male, 8 yo	15	40	100
Participant 11 Male, 7 yo	60	45	100
Participant 4 Male, 10 yo	0	0	100
Participant 3 Male, 10 yo	22	11	100
Participant 15 Female, 10 yo	75	75	75
Group 2 -Medium Moving Behavior			
Participant 13 Male, 9 yo	70	40	100
Participant 14 Male, 12 yo	50	50	95
Participant 7 Female, 6 yo	5	5	100
Participant 1 Male, 11 yo	20	45	100
Participant 9 Male, 7 yo	0	0	100
Group 3 - Low Moving Behavior			
Participant 6 Female, 3 yo	57	0	79
Participant 10 Male, 13 yo	20	50	100

Participant 18 Male, 12 yo	90	60	35
Participant 16 Male, 7 yo	50	95	47

Table 4. Coded behaviors associated with each Group by participant. Groups were created according to the first column - the percent of time spent engaged in Moving Behaviors. The numbers associated with each column represent percentage of time spent engaged in either a negative affective or positive affective state

	Pos Affect	**Neg Affect**
Group 1 - High Moving Behavior		
Participant 8 Male, 12 yo	0	0
Participant 5 Female, 6yo	73	0
Participant 4 Male, 10 yo	0	0
Participant 2 Female, 8 yo	25	0
Participant 17 Male, 8 yo	80	0
Participant 11 Male, 7 yo	25	0
Participant 4 Male, 10 yo	0	0
Participant 3 Male, 10 yo	22	0
Participant 15 Female, 10 yo	5	0
Group 2 -Medium Moving Behavior		
Participant 13 Male, 9 yo	65	0
Participant 14 Male, 12 yo	0	0
Participant 7 Female, 6 yo	5	5
Participant 1 Male, 11 yo	20	5
Participant 9 Male, 7 yo	0	0
Group 3 - Low Moving Behavior		
Participant 6 Female, 3 yo	21	0
Participant 10 Male, 13 yo	5	5
Participant 18 Male, 12 yo	40	0
Participant 16 Male, 7 yo	5	10

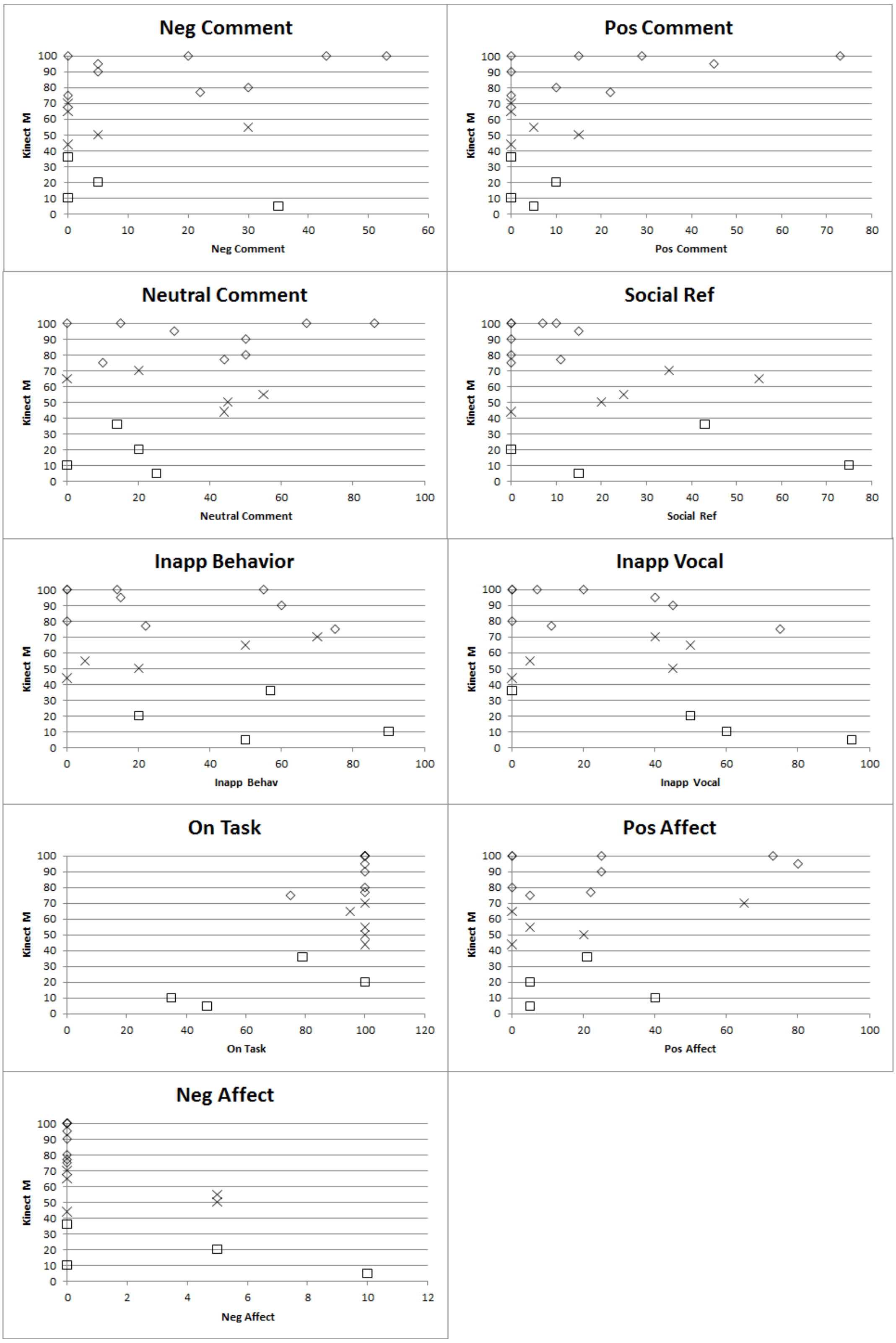

Figure 2. Scatterplot matrix of various coded behaviors plotted against Moving Behavior, the behavior that determined the grouping. Group 1 (High Moving Behavior) is represented by diamonds (◊), Group 2 (Medium Moving Behavior) is represented by crosses (X), and Group 3 (Low Moving Behavior) is represented by squares (□).

3.2 Generating Groups

Table 1 displays the results from the grouping effort. As mentioned earlier, we used the amount 'Moving' behavior as a way to segment individuals. Moving Behavior provides us with the level of engagement with the Kinect system. Moving Behavior can be relatively high or low for a variety of relevant reasons. For instance, low engagement with the system could stem from difficulty with attention, comprehension, or low motivation, all of which are seemingly prohibitive for proper use with our system. Commensurately, high engagement should signal an affirmation for each of these reasons, which would indicate that our CAI should work well with these individuals.

As a first pass attempt to classify individuals we adopted a total of three categories Low, Medium, and High Moving Behaviors. Each individual would belong to one of these categories. Visual inspection of the data reveals two things: (1) There is a broad range of Moving Behaviors, with individuals that are nearly constantly engaged to those having almost no engagement, and (2) Individuals seem to cluster toward higher levels of engagement, with two separate groups at around 50% Moving Behavior and another that falls well below 50%, starting at 36%. Likewise, we defined 'Low' Moving Behavior as individuals that were engaged in Moving Behavior in fewer than 50% of opportunities. Likewise, Medium and High indicated that participants engaged in Moving Behavior for 50-74% and 75-100% of their opportunities, respectively. From these groups we then mapped other relevant behavior to any consistent behavioral traits that emerged for each group.

The data presented in Table 1 also seem to indicate that certain behaviors appeared to coincide with Moving Behavior: Inappropriate Behaviors and On-Task Behavior. In order to more rigorously examination the relationship of Moving Behavior and other coded behaviors presented in Table 1, we produced Pearson correlation coefficients for each pair of data. The results are presented in Table 2. According to these results, it appears that Moving Behavior shares a positive relationship with On-Task Behavior and shares a negative relationship with Inappropriate Behavior and Inappropriate Vocalization, providing validity to the notion that examining Moving Behavior is a useful way to examine whether or not participants can successfully engage with the Kinect . Not surprisingly, Moving Behavior shares a negative relationship with the other Kinect-related behaviors, since these were mutually exclusive categories with Moving Behavior.

Figures 3-6 illustrate the mean behaviors for each group. Since one of the goals for our effort was to identify children that would be suitable for a Kinect-based CAI, we consulted several BCBA licensed therapists to help identify these group(s). Because no formal methods currently exist to help identify these individuals as this is the first known attempt to develop this type of a methodology, we relied on the clinical expert assessment of three licensed therapists. All therapists agreed that the group containing the least amount of Moving Behavior, Group 3, is not suitable for a Kinect-based CAI whereas Groups 1 and 2 are suitable. Groups 1 and 2 could be described as those participants demonstrating enough usability to be able to benefit from a Kinect-based CAI, whereas Group 3 exhibited behaviors that would be considered prohibitive for a Kinect-based CAI.

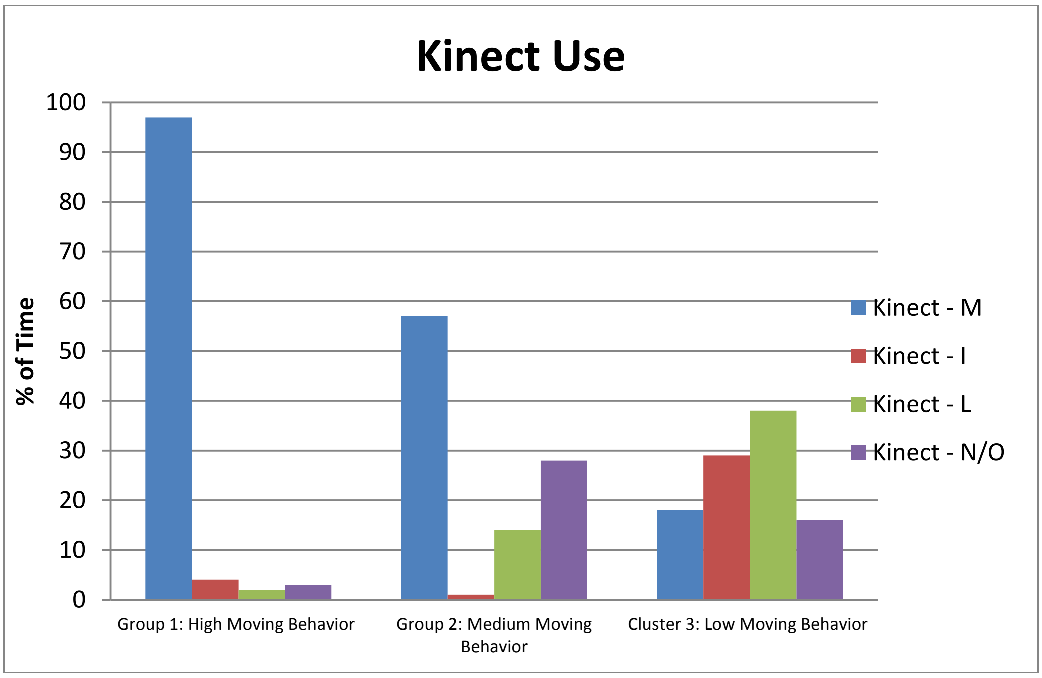

Figure 3. Graph of the average percentage of time each group engaged in various states of Kinect Use. Individual participant data is displayed in Table 1. 'I' refers to Inattentive, 'L' refers to Looking, 'M' refers to Moving, and 'N/O' refers to No Opportunity. Operational definitions for system interaction behaviors can be found in the Methods section.

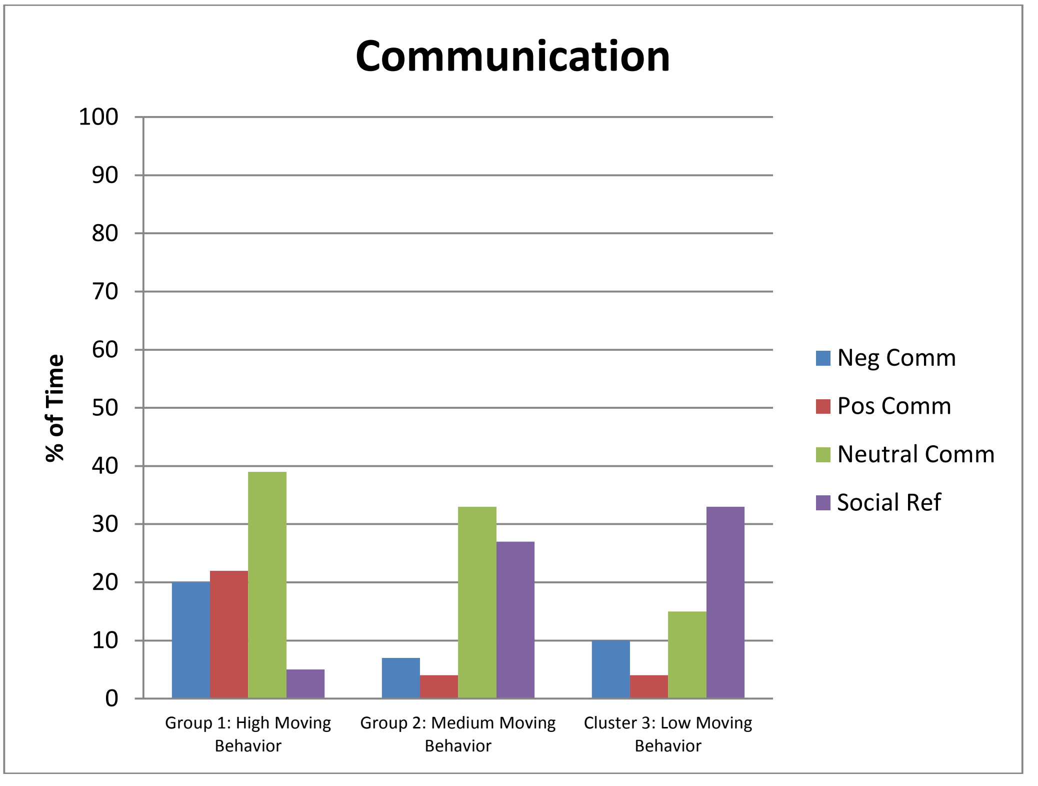

Figure 4. Graph of the average percentage of time each group engaged in various Communication behaviors for a given number of opportunities. Individual participant data is displayed in Table 1.

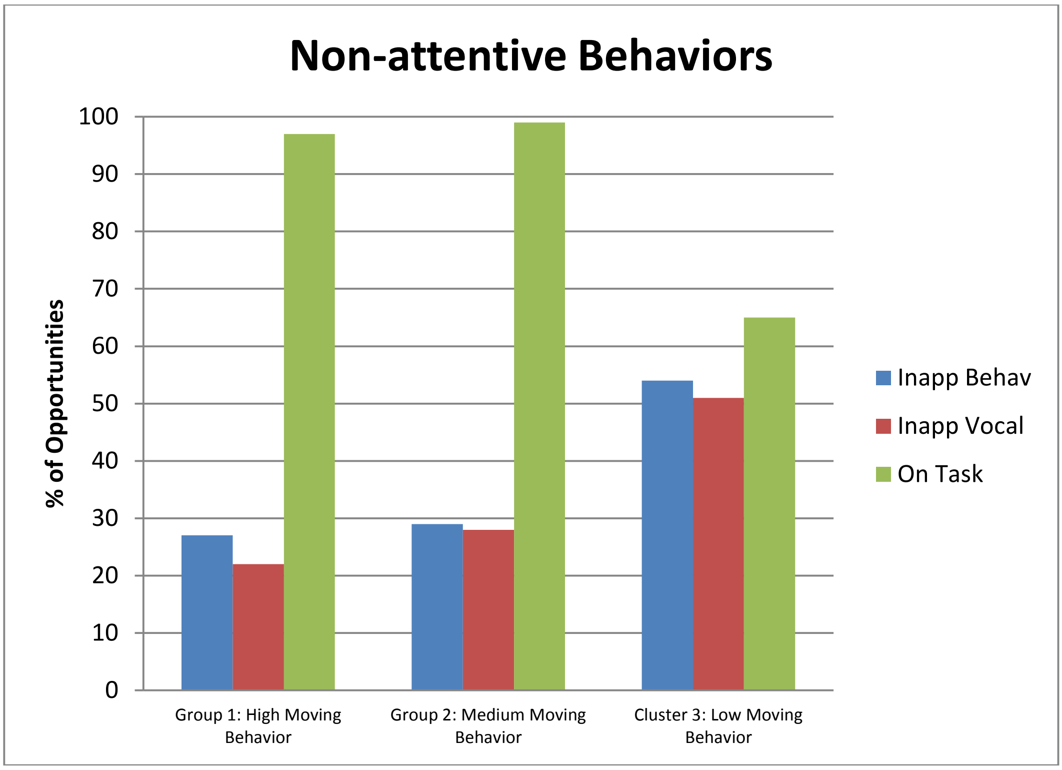

Figure 5. Graph of the average percentage of time each group engaged in various Non-attentive behaviors for a given session. Individual participant data is displayed in Table 1.

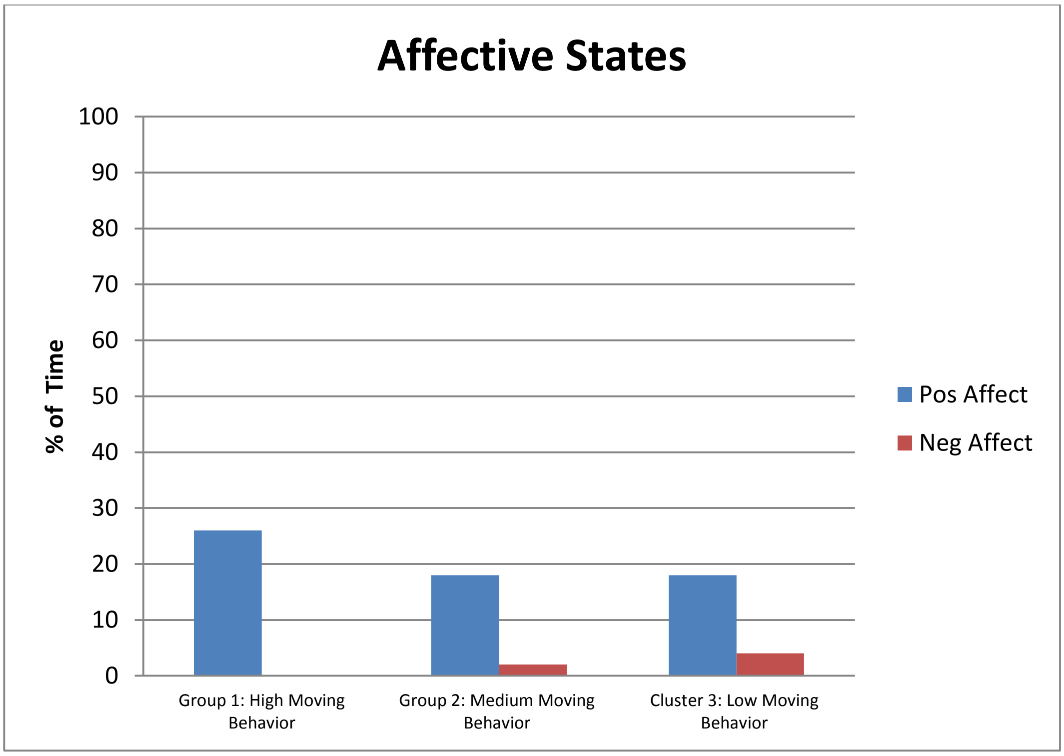

Figure 6. Graph of the average percentage of time each group exhibited various Affective states (Positive or Negative) for a given number of opportunities. Individual participant data is displayed in Table 1.

3.3 Candidate Target Skills

After determining that Groups 1 and 2 exhibited behavioral phenotypes suitable for Kinect interactivity, we then set out to identify the appropriate set of candidate therapy skills that will ultimately serve as the target for our development effort. A set of appropriate target skills were determined by two criterion. The first criterion is that the skill has clinical relevance. In other words, the groups of children determined suitable for Kinect use (i.e., Group 1 – High Moving Behavior and Group 2 – Medium Moving Behavior) exhibited a common need for the particular candidate skill. The second criterion is that the skill is feasible to build, from a game development perspective. We evaluated the clinical relevance by understanding which skills participants in Groups 1 and 2 needed based on their current therapy plans. This was accomplished by informally evaluating each child's Individual Education Plan or Functional Assessment, or both. This work was conducted in an informal setting with several experienced therapists independently. Once we determined which of the skills were most appropriate for each child, we looked for common, overlapping therapy skills. The resulting five skills emerged as candidate skills:

1. Safety skills
2. Following multi-step instructions
3. Turn-taking
4. Joint attention
5. Shared interactive play with peers

Therefore, our development efforts will focus on building and testing a Kinect-based CAI for one of those five candidate skills.

4. Discussion

The current manuscript describes a methodology for designing and developing a Kinect-based CAI to delivering in-home therapy for individuals diagnosed with ASD. Using this framework we narrowed the scope of our development by deriving examining children's ability to use the Kinect and from that, five potential candidate skills to target using the Kinect system that would benefit these children. This is important as no meaningful guidance exists for development of CAI for children diagnosed with ASD [30][24] . The DSM-IV and DSM-V classifications are not detailed enough to provide guidance for CAI development. Behavioral classification can better predict the clinical needs and skills of individuals with ASD specific to the CAI being considered for development, increasing validity and reliability of CAI use for each of the children.

One strong limitation of the current work is the amount of data collected. Although we feel the data we did collect was sufficient to inform the next stage of our development work, more data should lead to a more precise segmentation of individuals as well as the ability to meaningfully uncover predictive relationships between behavioral characteristics of an individual and the effectiveness of delivering therapy via Kinect-based CAI. In addition, it will be necessary to validate our methodology by incorporating data that indicates the effectiveness of our Kinect-based CAI for these individuals. The information gathered from this effort was a critical first step in understanding how to narrow our development effort to create a clinically effective and meaningful Kinect-based solution. Going forward it will be imperative to continually validate our research findings throughout our development in order to make sure we can maximize success in creating an effective tool. It is worth noting that similar published investigations often have sample sizes much smaller than ours. Generally speaking, more data will increase our ability to accurately group children with ASD based on relevant behavioral traits, further increasing the likelihood that we will be able to build an effective tool for children with ASD. Additionally, we need to better understand how IQ and language level overall affect CAI use. Based on our data it appears that language did not provide much predictive value with regard to understanding which individuals could successfully interact with the Kinect platform, a rather counterintuitive result. Still, more robust data should be collected to validate our results. With proper data sets, more formal grouping techniques could be employed yielding a greater ability to predict which individuals will benefit from a given CAI.

5. Conclusions

Developing effective CAI for children with ASD can dramatically improve the lives of these children and their families, as most children cannot access the amount of therapy deemed necessary. Although currently there is no shortage of available CAIs, it is not clear that any of them provide an effective means of augmenting current therapy. Developers may have a lack of understanding of how different children on the ASD may benefit differentially from the same technology. Further, some of these solutions may suffer from a lack of knowledge regarding the strengths and limitations of particular CAI platforms, ultimately limiting the effectiveness of those CAIs. The current manuscript aims to provide the first step at formalizing a methodology to help guide the design and development of CAI. Specifically, our four step methodology involves: (1) identifying a need where CAI is appropriate, (2) identifying a technology or set of technologies that are relevant for that population, (3) identifying an appropriate population that stands to benefit from our CAI, and (4) identifying specific content to be included in our CAI. The insights provided by such a methodology should substantially increase the likelihood of developing effective CAI than in the absence of these insights, which is largely how CAI is currently developed.

Although prior work has acknowledged the need for better guidance in developing CAI for children diagnosed with autism [30][24], the current literature offers little that goes beyond acknowledging that the heterogeneity among the population of children diagnosed with ASD should be taken into consideration when developing CAI [22] [23]. The present methodological development work attempted to go beyond the current wisdom by understanding the relevant variability among the population of children diagnosed with ASD. Going forward, the primary sequence of development efforts will include: (1) rapid, informal user experience testing with our Kinect-based CAI solution. This effort will examine fundamental elements of the solution, such as immediate user engagement and the ability to interact with the system. User experience data from this effort will be evaluated to better understand if we should then move onto a more formal effort in (2) understand sustained engagement of the solution over multiple sessions, as well as some initial feedback regarding the ability to successfully deliver therapy as well as other disruptive behaviors. If the results from (2) indicate we can experience success with our solution in delivering therapy we will formally compare the effectiveness of our CAI to the current standard of care to properly understand the potential benefit of our solution. This framework should greatly increase the likelihood of developing efficacious CAI for children diagnosed with ASD.

Our current effort was relatively focused in that we needed to develop an effective framework that would more intelligently guide our development on the Kinect system. However, we feel that this framework can be applied more generally to other CAI development efforts. Current reports on the development of CAI have not addressed the behavioral heterogeneity present in children with ASD. Understanding this heterogeneity has functional implications for how one might develop CAI, including an understanding which subset of children with ASD will be the user of the CAI as well as understanding which particular behaviors to target. The framework presented in the current manuscript can help intelligently answer these questions, ultimately providing effective CAI that augments current therapy, improving the overall quality of life for children and their families in a variety of ways.

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