Use of Augmented Reality with a Motion-Controlled Game Utilizing Alphabet Letters and Numbers to Improve Performance and Reaction Time Skills for People with Autism Spectrum Disorder

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Abstract

Augmented reality (AR) uses the real-world setting but enables a person to interact with virtual objects. In this study, we aimed to explore the use of alphabet letter and number in an AR task and its influence in reaction time in a population with autism spectrum disorders (ASD) compared with the performance of typical developing (TD) controls. We evaluated reaction time before and after AR tasks that consisted of identifying correct numbers and alphabet letters in 48 people with ASD and 48 with TD controls. Results indicate that total points for TD group were higher ($M_{TD} = 86.4$ and $M_{TD} = 79.0$) when compared with the ASD group ($M_{ASD} = 54.5$ and $M_{ASD} = 51.5$) for alphabet letters and numbers, respectively. Moreover, in analysis of reaction time results, only the ASD group showed an improvement in performance after the practice of an AR task. The control group was faster before ($M_{control} = 553.7$) and after ($M_{control} = 560.5$) when compared with the ASD group ($M_{ASD} = 2616.0$ and $M_{ASD} = 2374.6$, respectively). Despite the need for further studies, our results support that there is potential for clinical use of an AR task-based intervention for people with ASD.

Keywords: autism, virtual reality, virtual reality exposure therapy, augmented reality, serious games

Introduction

Autism spectrum disorder (ASD) represents one of the most common causes of neurodisability and developmental delay, occurring 1 in 68 children in the United States (Centers for Disease Control and Prevention [CDC]) and across Europe with prevalence rates ranging from 1.9/10,000 to 72.6/10,000 with a median value of 10.9/10,000. Children with ASD are less likely to attend school and commonly present with difficulty in acquiring literacy, leading to an academic disadvantage. Unsuccessful social experiences, family factors, and inability to engage with therapies, may further limit participation. According to Dennis, children who are at risk of potential deficits in early literacy skills often struggle with reading and reading-related activities in the formal schooling. Therefore, effective interventions to target these skills are critical.

It has been suggested that a multidisciplinary approach to supporting young people with ASD can be helpful in promoting successful education and better social participation. A novel element in multidisciplinary approaches lies in the use of assistive technology. Assistive technology has advanced rapidly over the last decade, establishing clinical utility in teaching people with cognitive disabilities new skills, as a permanent support, or as a temporary aid. A recent development that has been useful in educational inclusion is augmented reality (AR) applications. According to Crocetta et al., AR is a task that consists of the use of the real world as an environment, in which it is possible to visualize and interact with virtual objects, giving the illusion that the virtual and real world coexist. The main principle of a basic AR system is to superimpose computer-generated images on real-world images captured by a camera and then to display their combination on a computer.
In a systematic review of AR in educational inclusion in the last decade, the main advantages reported in the studies included increasing motivation, facilitating interaction, and maintaining the interest of students. In our own review, we have previously concluded that is a valuable tool, because ASD children’s interest is aroused by this technology, which they find attractive and motivating. AR applications can stimulate problem-solving skills for cognitive empowerment in typically or atypically developing children, as well as promoting inclusion and social integration as would be desirable in educational and group rehabilitation settings.

Research into AR-based social skills for people with ASD has also reported positive findings. AR rehabilitation approaches have been growing in recent years promoting increase in selective and sustained attention and active participation in realistic and interactive simulations. This has led to research interests in a range of everyday adaptive living situations, including living tasks, such as brushing their teeth independently, interventions to enhance social communication, and promotion of greeting skills.

One significant recent study is that of Guarnieri et al. in which an AR game called “MoviLetrando” was presented and demonstrated feasibility and reliability in use with 88 intellectually disabled young individuals, together with the game’s ability to provide similar and precise results on test–retest trials.

Guarnieri et al. provide a set of test materials and method that may be suitable for use with populations with ASD, but we do not know studies to date that have looked at this possibility. Thus, in the proposed study we wanted to determine whether it could be possible to facilitate improvement in 48 people with ASD (experimental group) and 48 people with Typical Development (control group) during the experience of alphabet letters (vowels and/or consonants) and numbers in an AR environment. Moreover, we used a reaction time (RT) task before and after practice with the AR game. According to Karalunas et al., computerized RT tasks are valuable as an indicator of cognitive performance and further, those tasks may provide a means of assessment, understanding, and rehabilitation of difficulties for individuals with ASD. To this extent, a task which facilitates improvement in RT, such as AR may also stimulate motor and cognitive abilities in this population. Within the study we aimed to explore whether people with ASD are able to play a game with reasonable cognitive performance (using alphabet letters and numbers) and if after practice they demonstrate improvement in reaction time.

We hypothesized that (H1) most of the participants would demonstrate improved performance during letters and numbers task, which would indicate that the game was accessible and could be successfully played (H2), reaction time would improve through AR game practice for the most of participants, but (H3) the ASD group would present with poor performance in the task during all protocols when compared with the control group.

**Methods**

**Ethics**

This study was approved by the Ethics Committee from Faculdade de Medicina do ABC (CAAE: 52541116.3.0000.0082 and No: 2.611.748) and the participants signed the consent forms. Participants under 18 accepted participation by informed assent forms and in this case their parents signed consent forms.

**Participants**

In this study we evaluated 96 participants, 48 in an ASD group and 48 in a typical development (TD) group. The participants in the experimental group (ASD) were selected from three associations that offer specialized educational services for the intellectually disabled, located in the cities of Vitória and Vila Velha, Espírito Santo, Brazil, and in São Paulo, SP, Brazil. We also recruited from an outpatient clinic of clinical neurology at a higher education institution in the city of Santo André, São Paulo, Brazil. The participants in the control group (TD participants) were selected from two public schools located in Potim, SP, Brazil.

A child neurologist and/or psychiatrist together with a multidisciplinary team confirmed diagnosis of ASD through patient history, psychological assessment, neuropsychological assessment, and evaluation of communication. The characteristics of the participants are shown in Table 1.

**Instruments**

**MoviLetrando game characteristics.** The computer game “MoviLetrando” was developed at the Laboratory for Research on Visual Applications in the State University of Santa Catarina, Brazil. It has been used in different studies (see Guarnieri et al. and Zangirolami-Raimundo et al.). The game uses the concept of projection-based AR with a webcam and creates a mirror images so that participants can see themselves on the screen.

As presented by Guarnieri et al., the MoviLetrando is a face-to-face learning computer program that involves interaction with a virtual symbol projected on the screen; letters of the alphabet (vowels and/or consonants), and numbers (1–10). The software allows the therapist or education professional to control different phases identifiable as alphabetic phases (AP) and number phases (NP). In each phase, the software offers various levels of difficulty (generating symbols on the left side, on the right side, or both sides; increase/decrease the number of symbols; increase/decrease the size of the symbols; increase/decrease in the time of the

<table>
<thead>
<tr>
<th>Variable</th>
<th>4.75 (3.5)</th>
<th>Left</th>
<th>Right</th>
<th>NI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of diagnosis, years, mean (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant hand, %</td>
<td>12.5</td>
<td>56.3</td>
<td>31.2</td>
<td></td>
</tr>
</tbody>
</table>

**Skills (He/She) Yes (%) No (%) NI (%)**

<table>
<thead>
<tr>
<th></th>
<th>Yes (%)</th>
<th>No (%)</th>
<th>NI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Writes</td>
<td>31.3</td>
<td>41.7</td>
<td>27.0</td>
</tr>
<tr>
<td>Writes the name</td>
<td>43.8</td>
<td>27.1</td>
<td>29.1</td>
</tr>
<tr>
<td>Makes copy</td>
<td>35.4</td>
<td>33.3</td>
<td>31.3</td>
</tr>
<tr>
<td>Identifies vowels</td>
<td>41.7</td>
<td>31.3</td>
<td>27.1</td>
</tr>
<tr>
<td>Identifies consonants</td>
<td>39.6</td>
<td>31.3</td>
<td>29.1</td>
</tr>
<tr>
<td>Identifies numbers</td>
<td>47.9</td>
<td>25.0</td>
<td>27.1</td>
</tr>
<tr>
<td>Naming vowels</td>
<td>43.8</td>
<td>27.1</td>
<td>29.1</td>
</tr>
<tr>
<td>Naming consonants</td>
<td>41.7</td>
<td>25.0</td>
<td>33.3</td>
</tr>
<tr>
<td>Can read simple words</td>
<td>27.1</td>
<td>45.8</td>
<td>27.1</td>
</tr>
<tr>
<td>Can read phrases</td>
<td>16.7</td>
<td>56.3</td>
<td>27.0</td>
</tr>
</tbody>
</table>

NI, not informed; SD, standard deviation.
exposure to symbols). For this study we choose two phases (one alphabetic with vowels and one number). The game shows a symbol (alphabetic or number according to the phase) in the middle top of the screen (Fig. 1) and the participant has to reach the same symbol, moving his/her hands in the virtual environment. The score, obtained from the game, is based on whether or not participants reached a symbol, whether it was correct, and the elapsed time taken to do each task.

**Total reaction time task: software TRT_S2012**

Although we had the objective to find out if people with ASD were able to play the game using alphabet letters and numbers, we were also interested to analyze if this practice could provide motor improvement. Thus, we chose to use a Total Reaction Time (TRT_S2012 Software) task that consists of presenting stimulus in the form of a yellow square in the center of the computer screen. The participant should react as quickly as possible by pressing the space bar on the computer. The software records the time between the appearance of the stimulus and the press of the space bar as a simple TRT with visual stimulus. The software was used by Crocetta et al.,26 Crocetta et al.,27 Antunes et al.,28 Herrero et al.,29 and validated by Crocetta et al.30 in a sample of 216 young adults, together with a mechanical validation using a robotic arm Crocetta et al.,31 with satisfactory validity and reliability.

**Procedures**

Each participant used the MoviLetrando while seated in front of a laptop computer, in a quiet room in the Institute. All the participants performed the same protocol without any previous practice and started with 14 trials of TRT followed by 4 minutes practicing AR games (2 minutes playing vowel game and 2 minutes number games). After this practice, all participants finished the protocol with another 14 trials of TRT to find out the influence of AR game in a motor performance task. During the AR game practice, in alphabetic phase (AP), two vowels were presented on each side of the participant, and only one is the target vowel (and the symbols are smaller than in AP). It is important to emphasize that in NP, there are more elements and the symbols are smaller than in AP, and it can interfere in the performance of the participant.

**Data analyses**

Statistical analyses were undertaken with IBM-SPSS (version 20.0.0; IBM Corp., Armonk, NY). Nonparametric statistical tests were used as the test scores were not normally distributed. The Mann–Whitney $U$ test was used to determine between group differences. Comparisons of differences in outcome between the ASD and control groups were evaluated using the Wilcoxon signed-rank test. The level of statistical significance (alpha) was set at $p<0.05$.

**Results**

The demographic characteristics of patients in the ASD group and the control group, including age and sex are summarized in Table 2. There were no significant differences between age of the two groups ($p>0.05$), except for sex.

The raw score results of the different variables of the MoviLetrando game (dependent variables) are presented in Table 3. For each of the two phases, the participant’s performance was indicated by multiple scores (total points, number of correct items, incorrect items, omissions, and average time to reach the vowel/number).

![FIG. 1. Alphabetic phase (a); number phase (b); participant performing the alphabet phase (c).](image)

**Table 2. Sample Characteristics of the Groups**

<table>
<thead>
<tr>
<th></th>
<th>Autism spectrum disorder ($n=48$)</th>
<th>Control ($n=48$)</th>
<th>$p$ (U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>11.0 (5.0)</td>
<td>11.8 (5.2)</td>
<td>0.520</td>
</tr>
<tr>
<td>Median</td>
<td>10</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>Min–Max</td>
<td>7–28</td>
<td>7–27</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>5F/43M</td>
<td>15F/33M</td>
<td>0.012</td>
</tr>
</tbody>
</table>

F, female; M, male; Max, maximum; Min, minimum; $U$, Mann–Whitney $U$ test.
A Wilcoxon signed-rank test showed that there was a significant difference ($p < 0.01$) between scores given for the alphabetic phase (AP) compared with the NP for most of variables measured. This result confirms the greater difficulty of the NP task, leading to a decrease in the total points and average time obtained by the control group. A reduction in the number of correctly reached numerical symbols (NP) compared with the number of vowels (AP) was also noted. However, these differences were significant only for the Control Group. There was no difference between NP and AP in the performance of the ASD group.

The Mann–Whitney $U$ tests indicated significant differences ($p < 0.01$) between groups on total points scored, correct symbols (AP and NP), mistakes in both phases AP and NP. Total points for control group was higher ($M = 86.4$ and $M = 79.0$) when compared with the ASD group ($M = 54.5$ and $M = 51.5$) for AP and NP, respectively. In considering average time there was no difference between groups.

In analysis of reaction time results, only the ASD group showed an improvement in the performance of the Simple TRT (see in Table 4) obtained after the AR task ($p < 0.01$). The control group was faster in the TRT obtained before ($M = 553.7$) and after ($M = 560.5$) when compared with the ASD group ($M = 2616.0$ and $M = 2374.6$, respectively).

To examine associations between performance during the practice (total points, correct, mistakes, omissions, and average time) and independent variables, such as (identifies vowels, identifies numbers, and naming vowels), we used the Spearman’s correlation coefficient. A nonsignificant correlation was observed between ASD participant’s characteristics and all variables of MoviLetrando game.

### Discussion

Our findings indicate that people with ASD were able to play an AR game with letters and numbers and that improvement in reaction time was observed after they performed the task.

### Comparison between performance on AP and NP

The results showed that the NP provided poorest performance when compared with the AP (total point, correct, and average time) but only for the TD group. We can speculate that the task demands for numbers presented a more difficult target (with smaller size of the objects and the greatest number of objects) and that this was the reason for the poor performance of the TD group. However, this difference was not found in the ASD group.

It might reasonably be speculated that there is an inherent bias that the participants with ASD had for number, which may reasonably explicate this trend. Hiniker et al.\textsuperscript{32} analyzed the numerical sense and the ability to rapidly assess numerical information using numerical acuity with arabic numerals and nonsymbolic array points. The results showed that number identification may be easier for individuals with ASD. Evidence supports greater proficiency for the use of numbers and numeracy in ASD.\textsuperscript{33} Iuculano et al.\textsuperscript{34} presented work, which indicates that children with ASD demonstrate better numerical skills in problem solving and possess advanced strategies for adding single-digit problems more often than TD individuals.

### Table 3. Test Performance of Both Groups in Alphabetic and Number Phases of MoviLetrando Game

<table>
<thead>
<tr>
<th>Moviletrando</th>
<th>Phase AP (vowels)</th>
<th>Phase NP (numbers)</th>
<th>AP vs. NP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ASD vs. Control</td>
<td>ASD vs. Control</td>
<td>ASD vs. Control</td>
</tr>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Total points</td>
<td>54.5 (25.5)</td>
<td>86.4 (19.4)</td>
<td>91.9 (23.6)</td>
</tr>
<tr>
<td>Correct</td>
<td>6.0 (4.1)</td>
<td>11.8 (3.0)</td>
<td>7.2 (3.8)</td>
</tr>
<tr>
<td>Mistakes</td>
<td>6.5 (3.7)</td>
<td>2.2 (2.1)</td>
<td>7.3 (4.2)</td>
</tr>
<tr>
<td>Omissions</td>
<td>1.5 (1.9)</td>
<td>0.3 (0.5)</td>
<td>1.2 (1.9)</td>
</tr>
<tr>
<td>Avg time</td>
<td>6.0 (0.6)</td>
<td>5.8 (0.8)</td>
<td>6.0 (0.6)</td>
</tr>
</tbody>
</table>

Note: significant differences are highlighted in bold ($p < 0.05$). AP, alphabetic phase; ASD, autism spectrum disorder; Avg, average in seconds; NP, number phase; $W$, Wilcoxon Signed-Rank test.

### Table 4. Test Performance of Both Groups in Total Reaction Time in TRT_S2012 Software (in Milliseconds), Before and After the Performance in MoviLetrando Game

<table>
<thead>
<tr>
<th>TRT (in milliseconds)</th>
<th>Anticipations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before vs. After</td>
<td>Before vs. After</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>ASD</td>
<td>2616.0 (1823.6)</td>
</tr>
<tr>
<td>Control</td>
<td>553.7 (436.7)</td>
</tr>
<tr>
<td>$U$</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Note: significant differences are highlighted in bold ($p < 0.05$). TRT, total reaction time.
Comparison of reaction times between groups

Only the ASD group presented with improvement in reaction times. This demonstrates that practice with an AR game can improve reaction times in participants with ASD and that RT is related to cognitive and motor performance (see Karalunas et al.22). This demonstrates that practice of an AR game can improve reaction times in participants with ASD. We do consider that this was perhaps an easy task for the control group from the outset, and so the controls did not improve after practice. This result is consistent with Morrison et al.35 who report that reaction time in ASD participants was slower than in a control group composed of individuals with typical development.

Moreover, the motor function of young adults with ASD was characterized by slower responses with decreased finger touch speed and overall hand dexterity, resulting in slower reaction times. According to Morrison et al.35 these motor responses may reflect the phenotype or phenosubtype of young adults with ASD and that this may be a useful marker of neuromotor dysfunction in this population. Herrero et al.29 investigated the performance of reaction time in ASD and TD participants after using a virtual reality (VR) task (typical laboratory timing coincident task) and the results indicated that individuals with ASD had the ability to respond to movements, and that the training in VR tasks had positive influence on reaction time; however, there was lower performance than typical development controls.

Implications and conclusion

Although AR approaches offer potential in improvement of educational resourcing for people with ASD, significant challenges exist in terms of integrating technology into any educational program, maintaining knowledge about what technology is available and what evidence exists to support the use of that technology.36 We conclude that the use of AR does have clinical utility and functional benefits for people with ASD. Furthermore, we note that the game using alphabetic letters and numbers (MoviLetrado), which encouraged participants with ASD to practice the task, promoted improvement with the practice, with further benefits in a reaction time test.

These results have implications for students with special educational needs, especially for those students with low levels of basic skills or low motivation and interaction that characterized our ASD sample. Based upon our findings, we advocate that multiple resources during education inclusion (including AR practice) can provide greater motivation, adherence to task, and a more engaging experience in the immersion of the educational process (see Quintero et al.11). We therefore consider that AR can offer a different and beneficial experience for people with ASD.

Other advantages of using AR include the professional’s ability to have greater control over all aspects of intervention, as well as greater engagement, acceptance, and less distraction.37 We conclude that the use of AR tasks, such as “MoviLetrado,” contributes to the development of new and beneficial approaches for people with ASD.

Limitations and future studies

Limitations include: (a) the lack of attention, motivation, cognitive, education level, and game experience measure-

ment may have influenced the results and discussion (see Quintero et al.11). Retrospectively, we consider that these data could have provided even better insight into our findings; (b) we used an alphabetic letter and number task, however, the improvement in touching those symbols could not be linked with literature level and learning process. Although some studies using AR applications used the correct scores before and after an intervention15,18,20 to analyze performance, future studies would be designed to understand the effect of literacy and/or numeracy in learning (reading level, writing ability, ability to identify alphabetic letters and numbers), and (c) the present study included a heterogeneous population with a wide age range and gender difference between groups (it was not possible to analyze gender or age differences). Furthermore, although ASD is considered a heterogeneous condition, and nonsignificant Spearman’s correlations were found with independent variables data, a more homogenous sample of participants could provide more specific results.

In future studies it would be appropriate to use different task in the AR environment not only looking at movement time and reaction time in a transversal protocol (short-term outcomes), but also considering a longitudinal protocol with a randomized control trial to provide long-term effect data. We also concur with previous findings reported by Wass and Porayska-Pomsta38 and Mesa-Gresa et al.39 that studies considering transfer of performance between environments should be the focus of further work. This focus should include, not only the improvement in AR, but the transference of this improvement to a real environment and its significance in educational settings. This could provide much more evidence about the use of AR as a rehabilitation tool for people with ASD.

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Author Disclosure Statement

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