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Differences in augmented reality games performance between individuals with down syndrome and individuals with typical development

Renata Thaís de Almeida Barbosa[a*], Tania Brusque Crocetta[b], Alan Patricio da Silva[a], Regiani Guarnieri[a], Thais Massetti[d], Jennifer Yohanna Ferreira de Lima Antão[a], Thaiany Pedrozo Campos Antunes[a], Celia Guarnieri da Silva[a], Marcelo da Silva Hounsell[b], Luiz Carlos de Abreu[a], Carlos Bandeira de Mello Monteiro[a,d,e]

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[a]Study Design and Scientific Writing Laboratory. Department of Community Health. Centro Universitário FMABC. Av. Príncipe de Gales, 821, 09060-650. Santo André, SP, Brazil;

[b]Universidade do Estado de Santa Catarina (UDESC). Av. Madre Benvenuta, 2007, 88035-901. Florianólpolis, SC, Brazil;

[c]Postgraduate Program, Master's Degree in Public Policies and Local Development, Escola Superior de Ciências da Santa Casa de Misericórdia de Vitória - EMESCAM, Espirito Santo, Brazil

[d]Rehabilitation Sciences Post-Graduate Program. Faculty of Medicine. Universidade de São Paulo (USP). Rua Cipotânea, 51, Cidade Universitária, 05360000, São Paulo, SP, Brazil;

[e]School of Arts, Sciences, and Humanities. Universidade de São Paulo (EACH-USP). Rua Arlindo Béttio, 1000, Ermelino Matarazzo, 03828000, São Paulo, SP, Brazil.

Corresponding author
profrenatathais@gmail.com

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Abstract

Introduction: Down syndrome is the most common genetic cause of intellectual disability, and the use of augmented reality can be improving the cognitive, motor, and literacy skills of this population.

Objective: to compare statistical differences in learning between individuals with Down syndrome and individuals with typical development using augmented reality games.

Methods: we compared the reaction time before and after the virtual reality tasks, in addition to the performance in these tasks, which consisted of correctly identifying numbers and letters in 46 people with Down syndrome and 46 controls with typical development.

Results: our results indicate that the total points for the typical development group were higher (M = 13.0 and 11.9) when compared to the Down syndrome group (M = 6.6 and 4.6) for letters of the alphabet and numbers, respectively. Furthermore, the results indicated that participants in both groups were more accurate in identifying alphabetic symbols when compared to numerical symbols, and both groups were sensitive to the number of symbols presented in each phase. The down syndrome group had a lower performance when compared to the typical development group.

Conclusion: despite the need for further studies, our results support the outcome that there is clinical utility of an intervention based on virtual reality tasks for people with Down syndrome. In conclusion, the use of this technology to improve the reaction time of this population is considered useful.

Keywords: Down syndrome, virtual reality, serious games, motor skills.

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Authors summary

Why was this study done?

This research is based on a very current topic and is consistent with international discussions among researchers investigating the use of virtual reality in learning for individuals with Down syndrome, focusing on the functional development of this population.

What did the researchers do and find?

In our study, we compared learning differences between individuals with Down syndrome (DS) and typically developing (TD) peers. The virtual reality tasks consisted of correctly identifying numbers and letters using the MoviLetrando game. A total of 46 individuals with DS and 46 controls (TD) participated. The results showed that the total letter and number scores were higher in the TD group than in the DS group.

Furthermore, participants in both groups identified alphabetic symbols more accurately than numerical symbols, with both groups being sensitive to the number of symbols presented in each phase. The DS group performed worse compared to the TD group.

What do these findings mean?

Based on the research results, the use of virtual reality has clinical utility and functional benefits for individuals with Down syndrome (DS), suggesting that these individuals understood the proposed task.

Highlights

There is the clinical utility of an intervention based on virtual reality tasks for people with Down syndrome;
The use of this technology to improve the reaction time of this population is considered useful;
The total points for the typical development group were higher when compared to the Down syndrome group.

INTRODUCTION

Down syndrome is the most common genetic cause of intellectual disability. Its incidence, in different populations, varies from 1 in 319 to 1 in 1000 live births[1,2]. Down syndrome is related to maternal age and has increased worldwide[3]. Down syndrome is caused by a complete or partial trisomy of chromosome 21[4]. In Brazil, the incidence is one case of Down syndrome for every 600 to 800 live births[5-7].

Down syndrome presents several brain alterations, such as maturation of the central nervous system, degenerative processes of the nervous system, regulation of neuronal apoptosis, and reduction in the release of neurotransmitters. This generates psychomotor delays (*e.g.,* cognitive deficits), hindering learning, speech skills, and gross and fine motor gestures[8]. According to Menghini *et al.,* (2011), short- and long-term memory performance, as well as visual-perceptual abilities, are impaired due to the dysfunction of different parts of the brain[9].

Individuals with Down syndrome need assistance in playing, understanding the rules of a game, and interacting with others[10,11]. These problems explain intellectual disability and reduced social skills[12], because social interaction is an important variable for a child's overall development. Social interaction begins in childhood, within the family, and in other environments (*e.g*., neighborhood, daycare, and kindergarten), and the conditions of the environments influence the quality of subsequent interpersonal relationships. As such, the child with special educational needs will relate to himself according to the environment[13].

According to Moriyama *et al.,* (2019), children and adolescents with Down syndrome need more time to acquire functional skills, and it is essential to offer assistance as soon as possible by parents, caregivers, and professionals. This suggests the need for professional support that is not restricted to school activities[14]. One of the ways to help in the development of these individuals is through technologies capable of including and generating social interaction[15], such as learning games, which enable cognitive and motor stimuli[16-18].

Assistive technology to aid literacy and communication of individuals with intellectual disabilities is being widely applied, however, little attention is being paid to augmented reality games[19]. According to Menezes *et al.,* (2015), individuals with Down syndrome respond positively to tasks that are different and complementary to conventional therapy, especially therapy involving virtual reality[20] or augmented reality[21,22].

The use of augmented reality in serious games allows the creation of learning situations and user immersion. This combination can even increase learning rate gains[21]. Games such as MoviLetrando and total reaction time (TRT_S 2012 Software), proved to be useful as a support in education, as they help to improve the cognitive, motor, and literacy skills of people with intellectual disability[22], autism spectrum disorder, and elderly[23,24]. Therefore, the aim of the present study is to compare statistical differences in learning between individuals with Down syndrome and individuals with typical development using augmented reality games.

METHODS

Ethical aspects

This study was approved by the Ethics Committee of Centro Universitário FMABC (report number: CAAE 54605616.5.0000.0082). All participants signed the free consent in informed consent. Participants < 18 old accepted to participate through the informed free assent in informed consent and, in this case, their parents signed the consent form.

Eligibility criteria

We included individuals diagnosed with Down syndrome, for the experimental group, and with typical development, for the control group, who were able to understand the instructions regarding the proposed task in each game and perform the necessary movement (without motor impairment of the limbs superiors). We excluded individuals who could not understand the guidelines regarding the proposed task, had some limitation of movement of the upper limbs and/or limitation in visual acuity that prevented them from playing the game, those who could not or did not want to complete the proposed task or who reported pain or discomfort while playing the games.

Participants

Participants were 46 individuals with Down syndrome, 20 females with a mean age of 21.1 years (SD=8.0); range 7–35 years; 26 males with a mean age of 21.1 years (SD=7.0); range 8–31 years; and 46 individuals with typical development, 25 females, with a mean age of 21.1 years (SD=7.0); range 7–33 years; 21 males, with a mean age of 19.3 years (SD=9.4); range of 8–39 years.

Participants in the experimental group (Down syndrome) were recruited from two associations that offer specialized educational services for people with intellectual disabilities, located in the cities of Vitória and Vila Velha, Espírito Santo, Brazil, São Paulo–SP. Participants in the control group (typical development) were recruited from two public schools located in Potim City, SP, Brazil.

Assessments and instruments

MoviLetrando game

A computer game that creates mirror images so participants can see themselves on the screen. Developed at the Visual Applications Research Laboratory at the State University of Santa Catarina, Brazil[25,26]. MoviLetrando makes use of augmented reality based on projection using a webcam, as presented by Guarnieri *et al.,*[22]. A face-to-face learning computer program that involves interacting with a virtual symbol projected onto the screen; letters of the alphabet (vowels and/or consonants) and numbers (1 to 10). The software allows the therapist or education professional to control nine different phases such as alphabet, numbers, and sets. In each phase, the software offers several levels of difficulty (generation of symbols on the left side, on the right side, or on both sides; increase/decrease the number of symbols; increase/decrease the size of the symbols; increase/decrease the display of symbols). In this study, we used two phases (an alphabetical phase, with vowels, and a numerical phase).

Game shows a symbol (alphabet or number according to the phase) at the top center of the screen (figure 1) and the participant must reach the same symbol, moving their hands in the virtual environment. The total game time is defined at the beginning and can vary from 2 to 5 min, in this study, 2 min were used. The score that each participant achieved is determined by whether participants reached a symbol, whether it was correct, and the time taken to complete each task.

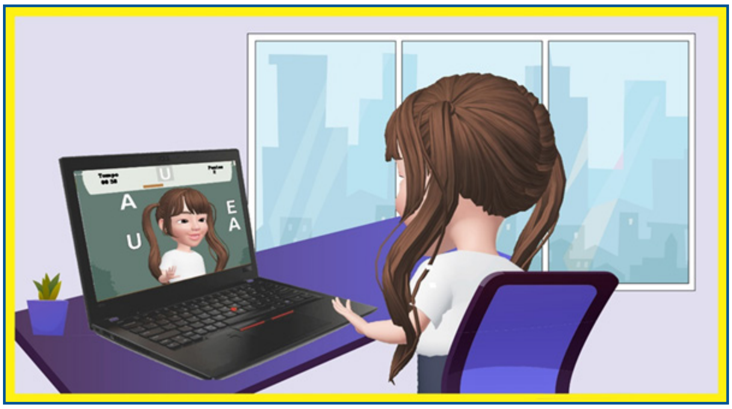


Figure 1: Participant performing the alphabet phase

Source: Prepared by the authors

TRT_S2012 Software

Total reaction time (TRT_S 2012 Software) was built and validated by Crocetta *et al.,*[27]. This software consists of promoting stimuli in the form of a yellow square in the center of the computer screen at previously defined time intervals. Participants must react as quickly as possible by pressing the space bar on the computer keyboard. The software records the time between the appearance of the stimulus and pressing the space bar (figure 2).

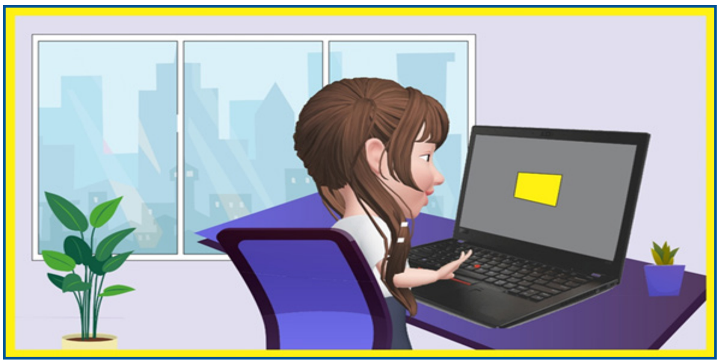


Figure 2: TRT_S2012 software with a yellow stimulus in the center of the screen. The participant reacted by pressing the space bar on the keyboard

Source: Prepared by the authors

Procedures

All participants performed the same research protocol involving two instruments without any previous practice. Sitting in front of a laptop, in a quiet room, they started with 14 attempts at TRT_S2012, followed by 4 min practicing MoviLetrando games, 2 min in the alphabetical phase using vowels (Phase A-5), and 2 min in the numerical phase (Phase C-5). After this practice, all participants finished the protocol with another 14 attempts on TRT_S2012. During the practice of MoviLetrando, in the alphabetical phase (Phase A-5), two vowels were presented on each side of the participant, and only one is the target vowel. In the numerical phase, three numbers were displayed on each side of the participant and only one number is the target.

Statistical analysis

Data were presented as mean ± standard deviation (SD) and analyzed using IBM-SPSS for Windows software (version 20; IBM Corporation). The normality of data distribution was not confirmed with the Shapiro-Wilk test. Mann–Whitney U test of independent samples was performed to analyze differences between groups for the total score, number of correct answers, incorrect answers, omitted answers, and mean time to reach the symbols in both phases. Non-parametric Wilcoxon tests were performed for group comparisons. Spearman's rank-order correlation coefficient was used to investigate correlations among age, sex, and reaction time.

RESULTS

Ninety-two (n = 92) participants met the inclusion and exclusion criteria. Namely, 46 in the Down syndrome group and 46 in the typical development group. There were no significant differences between the characteristics of individuals with Down syndrome and typical development (table 1).

Table 1. Characteristics of all participants

Variables	Down syndrome (n=46)	Typical development (n=46)	p-value
Sex (% female)	43.5	54.3	U = 0.30
Age, mean (standard-deviation)	21.1 (7.4)	20.3 (8.1)	
Median (years)	21.0	19.0	U = 0.43
Range of age (years)	7-35	7-39	

U: Mann–Whitney U test.

In testing the hypothesis that the Down syndrome and typical development groups differ in game performance, we used the Mann–Whitney U test to test the differences in all variables generated by the MoviLetrando game (table 2) and the performance of the total reaction time (TRT), generated by the TRT_S2012 Software.

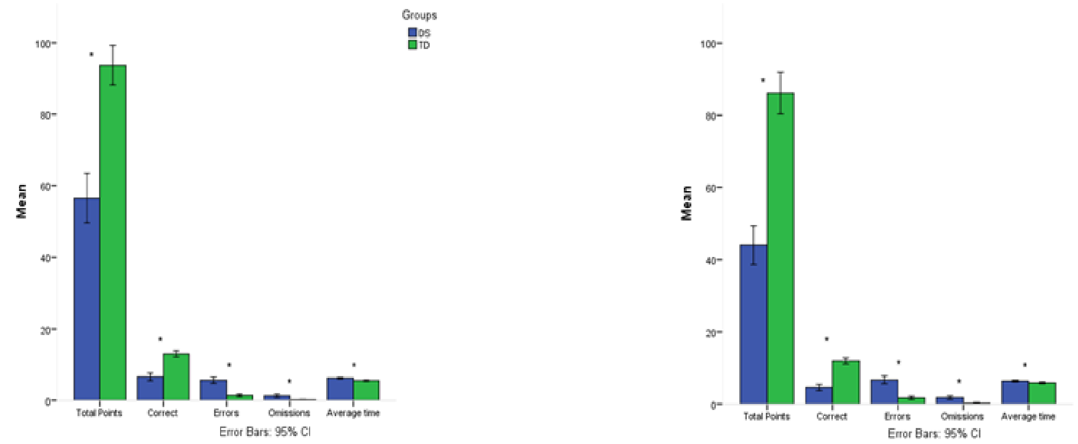
Means and standard deviations of the total score in the alphabetic (AP) and numerical (NP) phases of the MoviLetrando game indicated that the highest number of correct symbols was achieved by children with typical development (M = 13.0, M = 11.9) when compared to those with Down syndrome (M = 6.6, M = 4.6) for AP and NP, respectively. Significant differences were found among all the variables provided by the MoviLetrando game in both phases of the game (table 2). It was verified that the performance of Down syndrome is low when compared to the participants with typical development.

Table 2: Mean (standard-deviation) of the total score, individual answers, and mean time to reach the symbols, in the alphabetic and numerical phases of the MoviLetrando game. In the last two rows of the table the TRT was performed before and after the MoviLetrando phases

MoviLetrando variables	DS (n=46)	TD (n=46)	Outcomes (DS x TD)
Alphabetical phase			
Total score	56.6 (23.2)	93.7 (18.8)	U (92)=1915; p<0.001
Correct	6.6 (3.5)	13.0 (2.7)	U (92)=1949; p<0.001
Incorrect	5.7 (2.9)	1.4 (1.3)	U (92)=144.5; p<0.001
Omitted	1.3 (1.6)	0.1 (0.4)	U (92)=548; p<0.001
Mean time (seconds)	6.2 (0.7)	5.6 (0.7)	U (92)=363.5; p<0.001
Numerical phase			
Total score	44.0 (18.1)	86.2 (19.5)	U (92)=1951; p<0.001
Correct	4.6 (2.9)	11.9 (2.9)	U (92)=1991.5; p<0.001
Incorrect	6.7 (3.6)	1.7 (1.5)	U (92)=214.5; p<0.001
Omitted	1.8 (1.7)	0.3 (0.6)	U (92)=434; p<0.001
Mean time (seconds)	6.4 (0.8)	5.9 (0.7)	U (92)=605; p<0.001
Total reaction time (seconds)			
TRT before	2.6 (1.2)	0.4 (0.1)	U (87)=1.0; p<0.001
TRT after	1.9 (1.0)	0.4 (0.1)	U (85)=58.5; p<0.001

DS: Down syndrome group; TD: typical development group; U: Mann–Whitney U test.

Results indicated that participants in both groups were more accurate in identifying alphabetic symbols when compared to numerical symbols (table 3), with a high total score and correct symbols and low errors, omissions, and mean time to reach the symbols. This suggests a possible greater complexity in the numerical phase (figure 3).



a: alphabetical phase   b: numerical phase

Figure 3: Mean and standard-deviation of the total score, individual answers, and mean time to reach the symbols during phases (a) alphabetic and (b) numerical. The symbol * indicates a group difference between the Down syndrome and typical development groups at $p < 0.05$

Source: Prepared by the authors

Inspection of performance at the alphabetic and numeric phases suggested that accuracy declined in both groups, suggesting that the increase in the number of symbols to be reached may have played a role in how accurately participants correctly discriminated between the correct number to reach.

Summarizing, we can say that accuracy in both groups was sensitive to the number of symbols presented in each phase. The Down syndrome group had a lower performance when compared to the typical development group. Reaction time in the MoviLetrando and TRT_S2012 tests were examined for correlations with age and gender (table 4).

Table 3: Total score, individual answers, and mean time to reach the symbols, in the alphabetic and numerical phases of the MoviLetrando game. In the last column the differences between TRT performance before and after the MoviLetrando game

Total score	Correct	Incorrect	Omitted	Mean time	TRT	
	(AP x NP)	(AP x NP)	(AP x NP)	(AP x NP)	(AP x NP)	(B x A)
DS	W=242.5	W=121.0	W=667.5	W=460.0	W=619.0	W=97.0
	p=0.001	p<0.001	p=0.042	p=0.095	p=0.391	p<0.001
TD	W=185.0	W=185.0	W=441.5	W=47.0	W=889.0	W=540.0
	p<0.001	p=0.001	p=0.080	p=0.193	p<0.001	p=0.996

DS: Down syndrome group; TD: typical development group; W: Wilcoxon Signed-Rank Test; AP: alphabetical phase; NP: numerical phase; TRT: total reaction time; B: before; A: After.

a: Down syndrome   b: Typical development

Figure 4: Mean and error bars of the total score, individual answers, and mean time to reach symbols during the alphabetical and numerical phases for Down syndrome (a) and typical development (b) groups. The * symbol indicates a significant difference between the AP and NP phases at $p < 0.05$

Source: Prepared by the authors

Table 4. Spearman correlations on the time to reach the symbols and other measures of MoviLetrando

Variables	Age	Sex	TRT before	Time AP	Time NP	TRT after
Age		0.03	0.06	-0.18	0.02	0.11
Sex	-0.15		-0.15	0.17	0.38**	0.01
TRT before	-0.25	-0.06		0.10	0.05	0.62**
Time AP	-0.16	-0.04	0.08		0.20	0.39*
Time NP	-0.34*	0.00	0.21	0.67**		-0.10
Time after	-0.38**	-0.01	0.77**	0.21	0.40**	

Correlations are presented above the diagonal for the Down syndrome group and below for the typical development group. Time AP: mean time to reach a symbol in the alphabetical phase; Time NP: mean time to reach a symbol in the numerical phase; TRT: total reaction time. * p <0.05 (two-tailed); ** p <0.01 (two-tailed).

There were no significant correlations of time to reach the symbol in the MoviLetrando game (phases AP and NP) and TRT before this execution, however, there was a significant correlation of TRT afterward with AP for the Down syndrome group, and NP for the typical development group.

DISCUSSION

In this study, we found differences in performance between the groups. Both groups showed a similar pattern of decreased performance between the alphabetical and numerical phases. Antao *et al*.,[28] show similar outcomes when evaluating a population with autism spectrum disorder, in which the autism spectrum disorder group, the results showed that in PN the performance was lower when compared to AP. They suggested that the task demanded by numbers presented a more difficult target and that this was the reason for the lower performance.

According to Favero *et al*.,[29], children with Down syndrome have more difficulties in acquiring numerical skills than reading and writing skills. Thus, the acquisition of mathematical concepts and mathematical activities becomes complex for individuals with Down syndrome. According to Farias *et al*.,[25], as the number of generated symbols increases, the player is faced with situations in which he needs to reflect and develop less obvious movements to reach a certain letter that may be "behind" another letter, making the game more demanding in terms of the visual-motor aspect. Perhaps this explains the reason the typical development group also performed less well on the numerical symbol task.

There are need of effective intervention proposals, aiming at the acquisition of different areas of knowledge to improve the treatment quality and rehabilitation[30 31] . Farias *et al*.,[25] emphasize that the use of serious games with virtual reality technologies seems to be the appropriate type of software capable of promoting stimulation and adaptability and, at the same time, entertainment and playfulness.

In this study, participants with Down syndrome improved their reaction time after performing the virtual reality projection game task, while the typical development group maintained the same reaction time. Similar results were found in the study by Antão *et al*.,[28], who used a total reaction time task before and after the augmented reality game application in a population with autism spectrum disorder. It was observed that only the experimental group showed improvement.

In the study by Herrero et al.[32], the reaction time performance was investigated in participants of two groups, autism spectrum disorder, and typical development, after a virtual reality task (coincident time task) the results showed that the training had a positive influence on the reaction time of both groups, being typical development of greater expression.

CONCLUSION

The use of augmented reality games has clinical utility and functional benefits for people with Down syndrome. We noticed significant differences between the groups in the total points scored, correct symbols, and errors in the two phases. The total points for the control group were higher when compared to the group of individuals with Down syndrome.

Author Contributions

RTAB, TBC, RG, TM, JYFLA, TPCA, CGS, MSH, LCA, and CBMM: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflicts of Interest

The authors report no conflict of interest.

ORCID authors
Renata Thaís de Almeida Barbosa: ORCID: 0000-0003-0529-4178,
Tania Brusque Crocetta: ORCID: 0000-0001-7670-8943,
Alan Patricio da Silva: ORCID: https://orcid.org/0000-0003-2918-0060
Regiani Guarnieri: ORCID: 0000-0002-9690-3057
Thais Massetti: ORCID: 0000-0001-6386-0241
Jennifer Yohanna Ferreira de Lima Antão: ORCID: 0000-0003-4108-6843
Thaiany Pedrozo Campos Antunes: ORCID: 0000-0002-8682-1285
Celia Guarnieri da Silva: ORCID: 0000-0003-0006-2159,
Marcelo da Silva Hounsell: ORCID 0000-0002-9700-0909
Luiz Carlos de Abreu: ORCID: 0000-0002-7618-2109,
Carlos Bandeira de Mello Monteiro: ORCID: 0000-0002-2661-775X

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Resumo

Introdução: a síndrome de Down é uma das principais doenças genéticas que causam deficiência intelectual, e o uso da realidade aumentada pode aumentar as habilidades cognitivas, motoras e de aprendizado dessa população.

Objetivo: comparar diferenças estatísticas na aprendizagem entre indivíduos com síndrome de Down e indivíduos com desenvolvimento típico usando jogos de realidade aumentada.

Métodos: comparamos o tempo de reação antes e depois das tarefas de realidade virtual, além do desempenho nessas tarefas, que consistiam em identificar corretamente números e letras em 46 pessoas com síndrome de Down e 46 controles com desenvolvimento típico.

Resultados: nossos resultados indicam que o total de pontos para o grupo de desenvolvimento típico foi maior (M = 13,0 e 11,9) quando comparado ao grupo com síndrome de Down (M = 6,6 e 4,6) para letras do alfabeto e números, respectivamente. Além disso, os resultados indicaram que os participantes de ambos os grupos foram mais precisos na identificação de símbolos alfabéticos quando comparados aos símbolos numéricos, e ambos os grupos foram sensíveis ao número de símbolos apresentados em cada fase. O grupo com síndrome de Down teve desempenho inferior quando comparado ao grupo de desenvolvimento típico.

Conclusão: apesar da necessidade de mais estudos, nossos resultados suportam a utilidade clínica de uma intervenção baseada em tarefas de realidade virtual para pessoas com síndrome de Down. Em conclusão, considera-se útil o uso dessa tecnologia para melhorar o tempo de reação dessa população.

Palavras-chave: Síndrome de Down; realidade virtual; jogos sérios; destreza motora.