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A Technology-Based Intervention for Enhancing Cognitive Flexibility in Children with Autism Spectrum Disorder

Anamaria-Mădălina Sabou
Special Education Department, Faculty of Psychology and Educational Sciences, Babeş-Bolyai University, Cluj-Napoca, Romania
anamariamadalinasabou@gmail.com

Cristina Anamaria Costescu*
Special Education Department, Faculty of Psychology and Educational Sciences, Babeş-Bolyai University, Cluj-Napoca, Romania
christina.costescu@gmail.com
https://orcid.org/0000-0001-9329-9918

* Correspondence concerning this article should be addressed to christina.costescu@gmail.com

Abstract: *Cognitive flexibility is the most impaired executive function among children with autism spectrum disorder (ASD). Technology-mediated executive function training has several benefits for children with neurodevelopmental disorders. The aim of our study was to test the effectiveness of a digital intervention program to reduce errors in cognitive flexibility tasks in children ASD. To achieve our goal, we conducted a single-case experiment involving 3 participants with ASD aged between 9 and 14 years old. We used single-case experiment with alternative treatments to see if there are differences in cognitive flexibility when training was with or without technological tools. Based on the results, there was a decrease in the number of errors in both the technology-free and technology-based interventions, with no significant evidence of one intervention being more effective than the other. Future studies should include larger samples and increased number of intervention sessions.*

Keywords: *autism; cognitive flexibility; executive functions.*

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1. Introduction

Autism spectrum disorder is an early-onset neurodevelopmental disorder that is defined by a range of deficits in communication, social interaction, and restrictive, repetitive patterns of interests and activities, and behaviours (American Psychiatric Association, 2022). Among other factors that may influence the academic success and daily functioning of individuals with ASD, executive functions have gained a lot of attention lately. Studies have found several associations between executive functions and these restrictive, repetitive patterns of interests, activities, and behaviours (Turner, 1999; Boyd et al., 2009). Executive functions is an umbrella term encompassing a range of mental processes that are needed when we are going on automatic, relying on instinct, when intuition may be underdeveloped or impossible, and when we need to concentrate and pay attention (Diamond, 2013). Cognitive flexibility involves the ability to shift between different perspectives, tasks, or mental sets and to adjust to new demands or priorities and is highly important in complex task solving, such as multitasking or the identification of new solutions, marked by malleability when requirements are in change (Ionescu, 2012).

Among some of the characteristics associated with cognitive inflexibility are resistance to change, difficulty in transitions between different locations or events, restricted interests, or excessive preoccupation with certain objects or activities (Leung, & Zakzanis, 2014). Also, poor cognitive flexibility is shaped by perseverative, stereotypic behaviour and problems in regulating and modulating motor acts (Hill, 2004). The effects of deficits in cognitive flexibility have been primarily examined in two key areas: social interactions and everyday functioning. Difficulty in shifting focus from one task to another can result in heightened social anxiety. This is attributed to the need for quick integration of multiple auditory and visual cues within interpersonal relationships. Additionally, the tendency to focus on irrelevant details can interfere with goal-directed behaviour, making it challenging and disorganised for children with ASD to interpret social events (Demetriou et al., 2017; South, & Rodgers, 2017, Peristeri, Vogelzang, & Tsimpli, 2021). Classroom-specific behaviours in terms of cognitive flexibility can be defined as easily changing activities, adjusting behaviours that have been previously learned, and learning from mistakes, all these being essentially important for the learning process (Stad et al., 2018).

Several studies emphasise the potential advantages of developing targeted strategies to enhance cognitive flexibility within intervention programs (Varanda, & Fernandes, 2017). In this regard, several benefits of technology interventions targeting cognitive flexibility have been pointed out. It appears that children with ASD tend to achieve more significant results when performing tasks that are computerised (Kenworthy, et al. 2008). Some studies target cognitive flexibility as a single component and others incorporate cognitive flexibility alongside other executive functions, and the results are promising. Hardy et al. (2015) applied a cognitive skills training program, and significant improvements were evidenced for the experimental group for which training involving technological games was used compared to the control group where a crossword platform was used. The study evaluated and trained 4715 participants online. Both groups (control and experimental) were required to complete a session of approximately 15 minutes on at least 5 days of the week over 10 weeks. The intervention included a cognitive training program targeting a range of cognitive abilities, consisting of 49 exercises. The requirement for the control group was to complete as many crossword puzzles as possible, and the requirement for the experimental group was to complete the five tasks given in each session. The crossword puzzles were completed on a web-based crossword puzzle platform and the tasks administered to the experimental group targeted five domains of executive function. Based on the results, the treatment group showed substantial improvements in the five domains of executive function.

Another example is the ASTRAS platform for the assessment and training of executive functions in children which aims to assess and train selective attention, inhibition, cognitive flexibility, planning, and working memory. The results of its use showed satisfactory positive responses when children from both samples (typical/atypical development) interacted with the platform (e.g., they reported liking the platform, showing enjoyment, or finding it fun). Children found the software easy to use and a small percentage of them requested assistance from the therapist (Nappo et al., 2021).

Similarly, Maurya & Khan (2022) reported the positive effects of a cognitive training program on executive functioning, understanding cognitive mental states, and central coherence in children with ASD. While not directly focused on executive function training, Dai (2023) explored mindfulness as a potential intervention for improving cognitive flexibility in ASD children, concluding that mindfulness training could be beneficial. These studies indicate that various cognitive training approaches, including targeted cognitive flexibility interventions and mindfulness practices, may help improve cognitive functioning and derived competencies. Future research should address cognitive flexibility in particular and take into account the need to describe in detail the features of children with ASD in order to allow the development of some individualised and more efficient perspectives to optimise this executive function. Varanda & Fernandes (2017) proposed a study that aimed at improving flexibility and planning in which they included a total of 10 participants diagnosed with ASD who performed a series of play and games activities over 21 intervention sessions. Each week, 20 minutes of the speech and language therapy sessions attended by the children were allocated to play activities to improve this skill. Following the intervention, all participants demonstrated improvements in cognitive flexibility, indicating that the development of strategies to reduce deficits in this function may be highly beneficial for children with ASD. However, the intervention protocol does not include using technology tools.

Cognitive technology-based training in children with ASD presents significant potential but is not without its limitations. One primary challenge lies in the variability of individual needs and abilities within the autism spectrum. Children with ASD often exhibit diverse cognitive profiles, sensory sensitivities, and learning preferences, which can make it difficult to design technology-based interventions that are universally effective. Some other potential risks of technology use include: the digital divide which refers to a range of inequalities in access to technology, ethical issues, and privacy of data (Dolan, 2015). The study published by Dolan in 2015 emphasises that beyond the access itself or the presence/absence of a physical tool, it is about how this access is perceived with a focus on the overwhelming impact that socio-economic status has on the use of technology. Also in this regard, Mezhoudi et al. (2019) show in their study, a rigorous analysis of the risks that can occur when technology is used in children with autism across multiple areas, such as social and communication risks, activity design risks, and sensory issues.

Standardised programs may not account for unique challenges such as difficulties with communication, heightened sensitivity to stimuli, or atypical attention patterns. Therefore, a more individualised approach that uses repeated measurements over time, that assess within-subject changes before, during, and after the intervention, enables a more sensitive and precise understanding of how technology-based interventions influence cognitive flexibility. This type of design (i.e. single case experiment) also facilitates the establishment of a clear baseline measurement, allowing for stronger conclusions about the intervention's impact compared to natural variations in the child's behaviour.

2. Methodology

Our study aims to test the effectiveness of a digital intervention program in decreasing the number of errors made by children with ASD during cognitive flexibility tasks compared to a baseline period (e.g. when the child plays, and cognitive flexibility is not the target of the intervention).

Our hypotheses are a. the number of errors in the cognitive flexibility task is expected to decrease during the technology-free intervention phase compared to the baseline; b. the number of errors in the cognitive flexibility task is anticipated to be lower during the technology-based intervention phase compared to the baseline; 3. the number of errors in the cognitive flexibility task in the intervention phase is expected to be lower in technology-based training compared to technology-free intervention.

3. Participants

Our study investigated the effectiveness of the intervention programs for 3 participants who have a diagnosis of ASD, aged 9,12, and 14 years old. The inclusion criteria for the three participants were: being diagnosed with ASD, chronological age between 9-14 years, and deficits in cognitive flexibility (according to the interviews conducted with their psychologists). Two participants attend a mainstream school accompanied by a shadow and one participant attends a special school. The study conforms with the ethical standards required by the Ethical Committee of Babeş-Bolyai University. Informed consents were obtained from parents or legal guardians for each participant.

Participant 1 (P1) is a fourteen-year-old boy who attends a special school in sixth grade. In terms of *cognitive development*, P1 has a poorly developed level of narrative and verbal memory. He shows a poor ability to assimilate new information, to reorganise it, and to use this information to solve problems. He also has difficulties in situations where he needs to organise his knowledge flexibly according to context, purpose, or task demands. In terms of *attention and executive functions*, P1 currently has difficulties in terms of attention and executive function skills, relative to chronological age. It shows difficulties in selectively tracking auditory stimuli and changing sets, keeping a complex mental set activated, and adjusting a response to specific similar or different auditory stimuli. P1 has difficulty selectively engaging his attention to identify visual targets or has an impulsive response style, which leads to many committing errors. P1 also fails to inhibit his impulses to respond to distractors. On a conversational level, P1 can initiate and ask simple questions independently, he likes to talk about his passions. In terms of potential and strengths, it is noticeable that P1 has a range of interests that can be a starting point from which to build on training skills where difficulties have been highlighted.

Participant 2 (P2) is a nine-year-old girl who attends a mainstream school for 4 hours daily, her curriculum is adapted for children with special educational needs and she attends the classes with a shadow. In terms of *cognitive development* P2 can complete simple tasks with the help of an adult, but the time spent on tasks involving cognitive processing and attentional inhibition is low and below chronological age. P2 can recognise name objects, indicate different categories, and distinguish colours. In terms of *attention and executive functions*, P2's attentional focusing ability is below the expected level according to chronological age. P2 can maintain attention for limited periods of time (7-12 minutes) in tasks and activities that are of interest to her, but the attentional focus is below the expected level in specific tasks that require focused attention. She is easily distracted and has difficulties inhibiting her impulses. She has some difficulties in selectively tracking auditory stimuli and switching sets, to keep a complex mental set activated and to adjust a response to specific auditory stimuli, similar or different. P2 also fails to inhibit her impulses to respond to distractors. The girl has exertional capacity and endurance below expected levels relative to chronological age, fatigues, and loses focus on complex cognitive tasks. Conversationally, she can initiate and ask simple questions independently. P2 can develop symbolic games or spontaneous play sequences appropriate to chronological age. Fixations and stiffness can also be redirected in a relatively short time.

Participant 3 (P3) is a twelve-year-old girl who attends a mainstream school in Cluj-Napoca, with a permanent shadow. In terms of *cognitive development,* P3 can complete simple tasks with the help of an adult, but the time spent on tasks involving cognitive processing and attentional inhibition is low and below chronological age. P3 loses focus on complex cognitive tasks. She finds it difficult to persevere with difficult tasks, but she succeeds in completing simple tasks independently. P3 can group objects according to criteria such as shape, colour, and category, and knows the facial/body schema. In terms of *attention and executive functions*, P3 shows attentional instability, her attentional concentration capacity is below the expected level, and P3 manages to maintain attention for limited periods of time (12-17 minutes) in tasks and activities that are of interest to her, but attentional concentration is below the expected level (4-6 minutes) in specific tasks that require focused attention. Distractibility is marked, especially in tasks that exceed her level of receptive comprehension. She also has difficulty switching attention to a new task or within the same task from one task to another. She has difficulty focusing on specific details and finds it difficult to pay attention to several aspects at once. P3 has difficulties in inhibiting impulsive responses. Time spent on tasks involving attentional inhibition is low and below chronological age. In the case of participant, P3, difficulties in planning and problem-solving are evident. She can come up with a new ending to familiar stories but has difficulty planning and figuring out accurately when she should complete some activities. She can describe the outcome of simple action sequences but has difficulty expressing logical relationships between concepts. She uses phrases to speak, and she communicates her needs easily.

4. Research design

The type of research we chose is the single-subject experiment, alternative treatments design. We used this type of design to study comparatively and simultaneously the effectiveness of two intervention techniques (cognitive flexibility training without technology, and cognitive flexibility training with technology). In the first phase, we established the baseline level of cognitive flexibility. In the second phase, we alternatively implemented the two techniques to be compared. The order of the two types of intervention was randomly set and randomised. We chose this type of design because it allows us to simultaneously evaluate the effectiveness of both interventions within the same study, to reduce the confounding effects of individual differences by providing each participant exposure to both conditions. It fosters direct, within-subject comparisons, ensuring that observed differences in cognitive flexibility are attributable to the interventions rather than extraneous factors. Furthermore, an alternative treatment design is time-efficient, as it avoids the need for separate control groups for each intervention, and is ethically favourable, as all participants gain access to potentially beneficial treatments. This approach is also well-suited to capturing nuanced, context-dependent responses, enabling us to explore how children with ASD uniquely engage with technology-based methods versus technology-free interventions, thus yielding richer, more applicable insights for tailoring interventions. Also, this type of design allows a visual analysis of the data, which encourages carefully examining every aspect of the data to determine sources of variability rather than just overall effects.

5. Instruments and procedure

To assess cognitive flexibility in both the baseline and intervention phases, we used the task called *Geometric Figure Road* from an assessment tool *REMEX: a scale for executive functions and emotion regulation in children* (Costescu et.al. 2024), which measures executive functions and emotional regulation in children with ASD and other neurodevelopmental disorders. The task involves identifying certain symbols by the participants according to the indicated rules. The rules change after every two rounds, and participants must follow the new rules in order to solve the task. For each session, both in the baseline and intervention phase, we created modifications to the task to avoid participants' familiarisation with it. Modifications included: formulating different rules, adding geometric figures, and so on. The evaluation criteria consisted of the total number of errors. The following were categorised as errors: marking with the wrong symbol, missing a certain symbol, and marking a figure other than the one(s) mentioned. A score (number of errors) was calculated for each baseline and intervention session.

In the intervention phase for technology-free training we used 3 games. The first game used is called *Tangram*, a puzzle game. It consists of 7 pieces: one square, 3 triangles and one parallelogram and the task is to reproduce certain patterns. The game develops cognitive flexibility as well as visual memory, logical analysis, hand-eye coordination and perception. Description of the game: the game involves putting pieces together to make patterns. First, the experimenter does one pattern, then the child is asked to pay attention to reproduce the pattern. Given that the participants' memory was predominantly visual, we also provided them with the models drawn from the model booklet.

The second game used is called *Mastermind* game. It is a game that consists of matching 3D pieces on a 2D game board according to certain patterns. Description of the game: like the first game described, mastermind game is a game that aims to reproduce after the model. The first time the experimenter made the model and asked children to pay attention so that they could reproduce the model. We also provided them a picture of the model. The game is supposed to train cognitive flexibility, concentration, problem solving, spatial perspective according to the game instructions.

Another game used is the *Lynx* game which involves overlaying cards that illustrate certain images on the board, where the items/objects are located. The player must look for the images on the playing surface - on the board. Description of the game: before starting the game, the experimenter explained to the participants the rules of the game, which consisted of matching cards illustrating certain images with the same image on the board. The aim of the game was to find as many images as possible and to mark this identification by superimposing the card on the board in the corresponding places. The skills this game trains are cognitive flexibility, attention, and dexterity, according to the game instructions.

In the intervention phase, we used a digital app for cognitive flexibility training with technology. The *Luminosity* app is an app created by researchers testing a range of cognitive skills training methods, adapting certain tasks or creating certain tasks of their own. *Luminosity* transforms a series of tasks in the lab and turns them into fun games. The game creation has a fun theme in the background, and the training is fun and challenging through the careful selection of features to bring each game to life. The effectiveness of the app has been proven several times in research studies (Al-Thaqib et al., 2018). From this application we have selected a series of 3 games to train cognitive flexibility. The first game is called *"Ebb and Flow"* and is based on the process of adapting to changing circumstances, moving from one goal to another. In the game, lots of moving yellow or green leaves appear on the screen. When the green leaves appear on the screen, the child must swipe the leaf in the direction in which the tip of the leaf is pointing, and when the yellow leaves appear, the child has to swipe the leaf in the direction in which the tip is moving. The second game is called *"Space Trace"* and is all about spatial fluency - the ability to quickly generate new patterns. This game involves joining five dots to create a constellation, the condition being that each time a new pattern is created. The name of the third game is *"Disillusions",* a game which emphasises the process of adapting to changing circumstances, moving from one goal to another. This game involves creating puzzles by adding missing pieces, with changing rules as follows: when the shape to be added is upright, it must be placed next to a shape that has the same colour, and when the shape to be added is horizontal, it must be placed next to a shape that has the same symbol on it as the missing shape. The games were delivered using a mobile phone.

6. Procedure

The study was run in conformity with the ethical standards required by the Ethical Committee of Babeş-Bolyai University. Informed consents were obtained from parents or legal guardians for each participant. First, there was a settling-in phase which included a series of sessions in which the child had the opportunity to familiarise him/herself with the person who was to implement the intervention. Secondly, the baseline phase was implemented, and then in the third phase the intervention sessions were carried out. The baseline phase included 6 sessions/participant, and the intervention phase consisted of 12 sessions/participant. At the end of each baseline and intervention session an evaluation was conducted. The number of errors made by the child after each session on the *Geometric Figure Road* task were recorded by the experimenter both in baseline and in intervention phases.

7. Phases

A. Baseline Phase: The baseline phase consisted of six sessions per participant, during which cognitive flexibility was not the target of the intervention. Children played freely with the psychologists and at the end of the 10 minutes play they completed the *Geometric Figure Road* task.

B. Intervention phase. At intervention stage we conducted the two types of training. At the beginning of each session, we explained to the participants the rules of the games, after which they were involved in the game for 10 minutes in each session. For all three participants the intervention was carried out in the private psychology office they attend. The intervention was implemented in a playful atmosphere that did not constrain, create discomfort for the child or any other type of unwanted feeling or state, and where appropriate breaks were taken to avoid overloading the child.

For each participant the time spent both in the training without technology and in the training using technology was 10 minutes. Before each session the rules were explained to the children with the necessary adaptations according to the developmental level of each participant. We also checked if participants were familiar with the geometric figures and explained the rules to them before the assessment.

8. Data analysis

To test the set hypotheses, we first compared the number of errors in the cognitive flexibility task in the two phases of the experiment, baseline and intervention, respectively the number of errors in the cognitive flexibility task in the technology-based training compared to the no-technology training in the intervention phase. For this purpose, we used visual analysis of the graphs, considering the following indicators: within-phase- level (high, medium, low), trend (upward or downward)/magnitude (numerical differences between the values in the two phases), variability (stable, variable, highly variable); between-phase- overlap, consistency, latency. Data for all three participants were presented as graphs. This was valuable to visualise the data but also to make a number of valid comparisons. This type of analysis is used generally and specifically in this research to determine whether the presence of a functional relationship between independent and dependent variables.

To determine if statistically significant relationships exist between baseline and the two kinds of intervention: technology-free intervention and technology-based intervention, we also conducted statistical analysis using a Wilcoxon non-parametric test. The exact identification of the stages at which statistically significant differences were generated was possible with this analysis.

9. Results

This study was conducted over approximately three months from mid-December through the end of March 2024. The number of measurements was: six measurements in the Baseline; twelve sessions in the intervention phase for each participant, of which six sessions were training without technology and six sessions were training with technology. For all three participants, the efficiency of the two types of training was determined by reference to their pre-intervention (baseline) performance.

9.1. Visual data analysis

Participant 1:

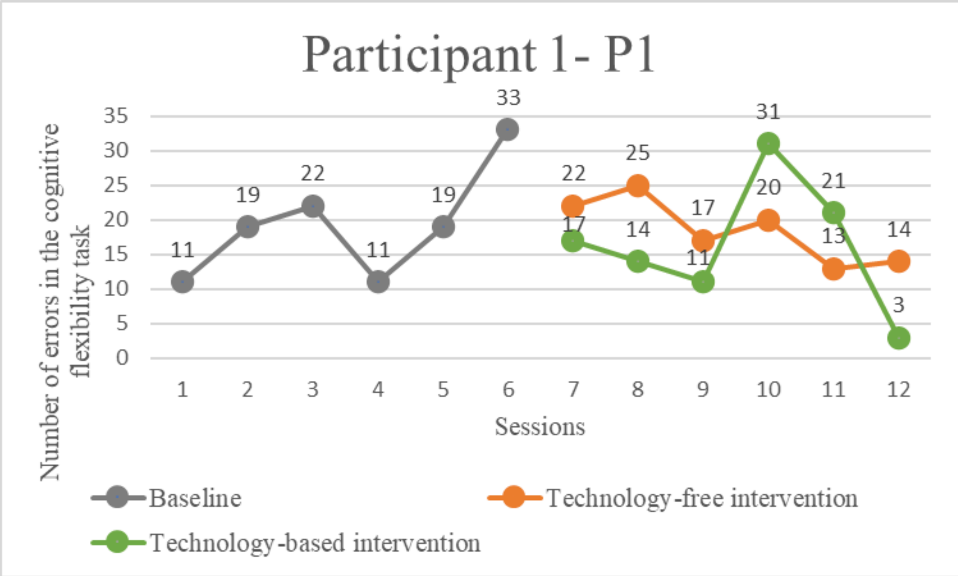

Figure 1. Results of Participant 1 in the baseline and intervention phase.

In the baseline for P1 we identified a medium level. The level represents the amount of behaviour that occurs or the average (mean) of data within a phase. During the intervention phase for the technology-based intervention, a medium level is also identified, the same as in the intervention without technology. Although the level remains average across all phases, P1 managed to reach much lower values in the cognitive flexibility task in the technology-based intervention compared to reference level. Thus, in the technology-based intervention he managed to reach a total of 3 errors (the lowest point on the graph in this phase) as well as in the technology-free intervention where he managed to reach a total of 14 errors compared to the baseline from which he started with a total of 33 errors (the highest point on the graph in this phase).

The second indicator the trend, refers to the slope of the best-fit straight line (trend line or line of progress) describing the direction of data which can be upward, downward or flat. In our case: upward trend indicates an increase in the number of errors in the cognitive flexibility task, downward trend indicates a decrease in the number of errors in the cognitive flexibility task. For P1 it is upward in the baseline phase, downward in the intervention phase without technology, which means a lower number of errors in the cognitive flexibility task. In the technology-based intervention phase the trend is slightly downward which shows a slightly lower number of errors in the cognitive flexibility task. The magnitude is gradual in the baseline as well as in the no technology intervention, and in the technology intervention the magnitude is steep from mid-intervention.

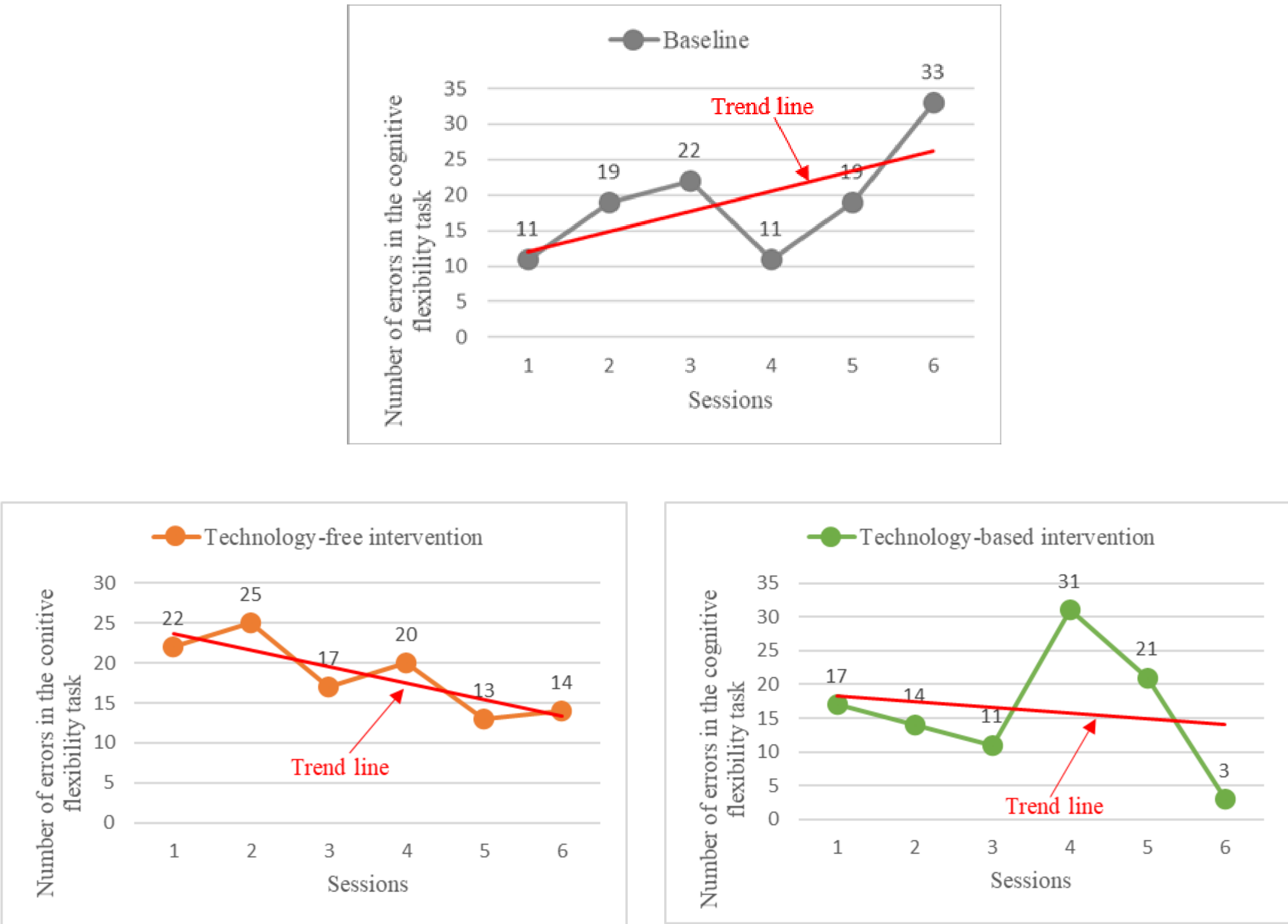

Figure 2. Data trends for Participant 1.

As for the third indicator, variability (the extent to which data vary or fluctuate from one session to the next session), the graph shows a stable baseline, a stable technology-free intervention and a slightly variable technology-based intervention. Another indicator is latency or immediacy of effect, and it refers to the how fast the data pattern changes when one phase ends and the next one begins. The more immediate the change is, the stronger the effect of the intervention on the behaviour. When examining the data between phases for P1, there is an immediate effect observed both between the baseline and the no-technology intervention and between the baseline and the technology intervention. This indicates that effects are already occurring from the very first intervention session.

Overlap represents the number of data points in one phase that are in the same range of values as data in subsequent phases. The smaller the overlap, the better the indication that the intervention has changed the behaviour. In the case of P1 was calculated as the number of overlapping points: total points x100= percentage overlap. Thus, there is an overlap of one point in the mid-range between the baseline and the intervention without technology, as well as between the baseline and the intervention with technology. The overlap percentage for both types of intervention is 16.6% (1:6x100=16.6%). We also identified a functional relationship between the baseline phase and both types of intervention.

Participant 2:

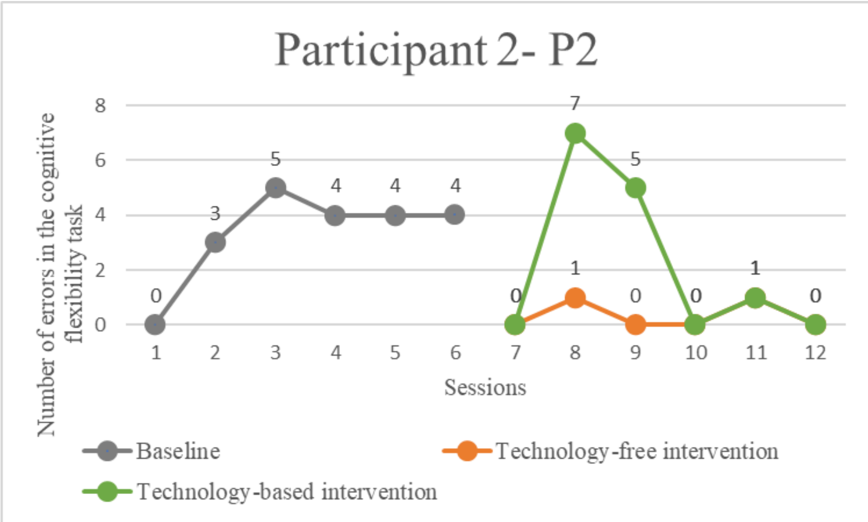

Figure 3. Results of Participant 2 in the baseline and intervention phase.

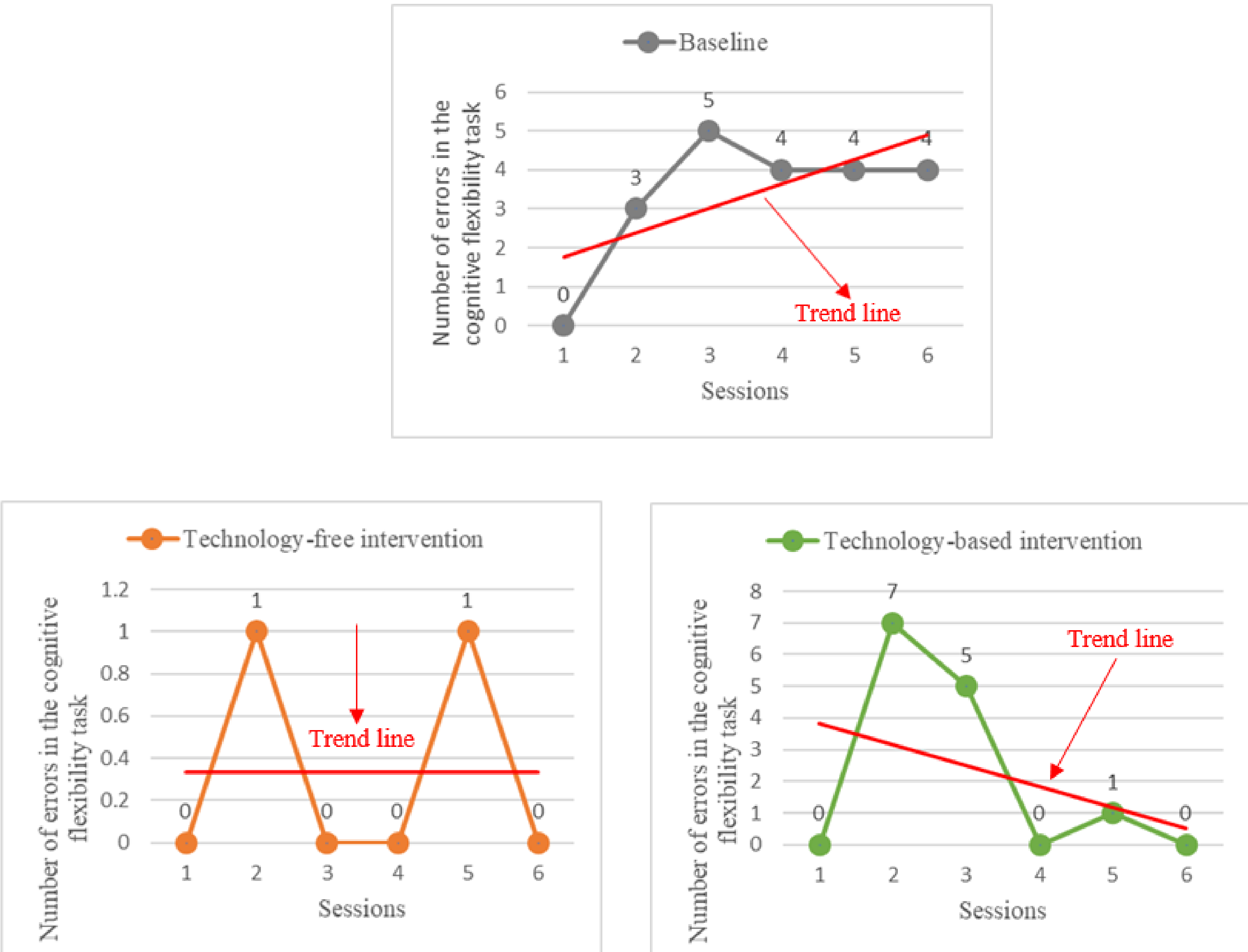

Figure 4. Data trends for Participant 2.

In the Baseline phase for P2 we identified a medium level. In the Intervention without technology there is a low level, and in the Intervention with technology there are two levels: low and high. The trend is upward in the Baseline phase which indicates an increase in the number of errors in the cognitive flexibility task, and flat in the Intervention without technology phase. In the intervention phase with technology the trend is downward, indicating decreases in errors in the cognitive flexibility task.

Magnitude is gradual in the baseline phase. In the no-technology intervention, given that the trend is flat, the magnitude does not apply. In the technology-based intervention phase the magnitude is steep from the second intervention session. Thus, it shows a large difference between the baseline in which P2 made a total of 20 mistakes in all the 6 sessions, and the Technology-free Intervention phase in which he made only two mistakes, the difference is a major one of 18 points. Between the baseline and the Technology-Based Intervention, the difference is a smaller one of 7 points (baseline 20 points, Technology-Based Intervention 13 points). As for the third indicator, namely variability, the graph shows a stable baseline, a stable technology-free intervention and a slightly variable technology-based intervention. In the case of P2, there is immediate effect both between baseline and intervention without technology and between baseline and intervention with technology, which indicates visible effects from the first intervention session.

The second participant showed a lower number of errors in the technology-free intervention phase compared to the technology-based intervention phase (see Figure 3), and a possible reason could be sensory particularities. In the sensory area, a number of sensory needs, auditory needs (e.g. disliking loud sounds) or the presence of fixations on certain objects were highlighted. In the technology-based intervention, through qualitative observation, distractions related to the background sound of the game or movements of the head position when a series of moving visual stimuli appeared on the screen were noted.

Participant 3:

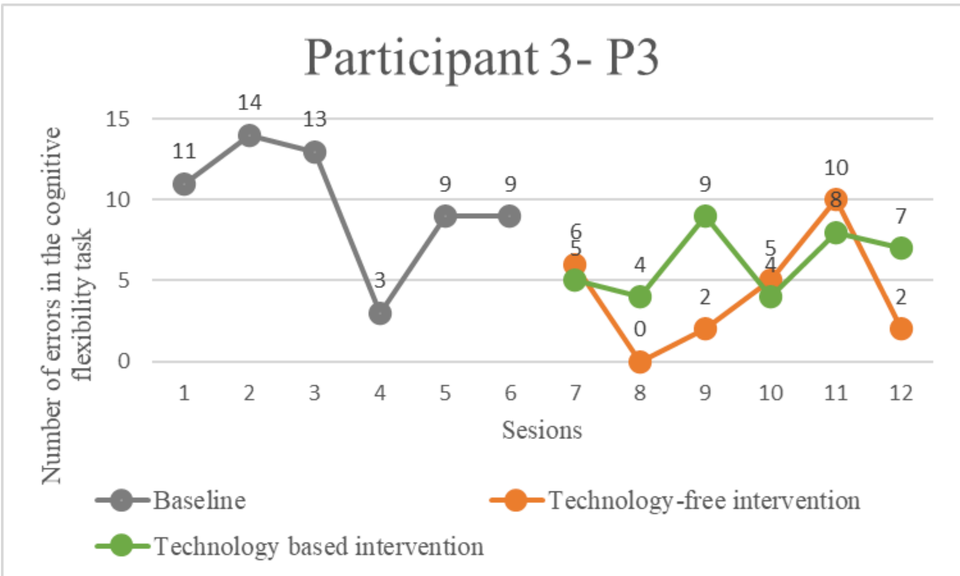

Figure 5. Results of Participant 3 in the baseline and intervention phase.

The Baseline data for Participant 3 has two levels: medium and high, the Intervention without technology has a low level and the Intervention with technology has two levels: low and medium. The trend is downward in the Baseline phase, slightly upward in the no technology intervention phase and in the technology intervention phase.

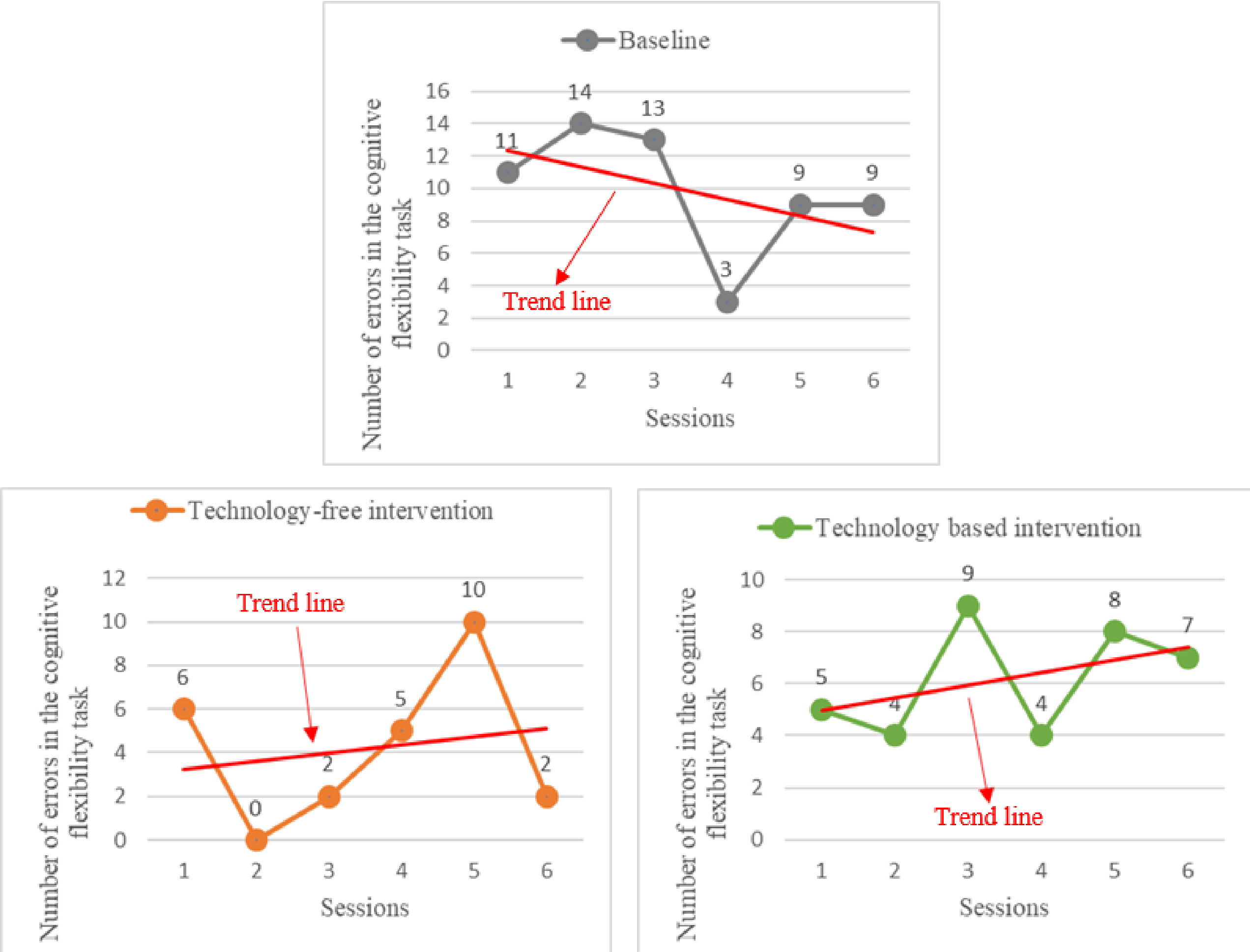

Figure 6. Data trends for participant 3.

The magnitude is steep in both the baseline phase and the no-technology intervention phase. In the technology-based intervention phase the magnitude is steep. It shows a large difference between the baseline phase, where P3 scored 59 points out of 6 sessions, and the Intervention without technology phase, where he scored 25 points out of 6 measurements (difference being 34 points), and the Intervention with technology phase where he scored 37 points out of 6 sessions (difference being 22 points). Data shows an immediate effect both between baseline and intervention without technology and between baseline and intervention with technology, which highlights effects from the first intervention session.

9.2. Improving participants' scores in technology-based training

For Participant 1, we can notice an increase of the scores in the cognitive flexibility games since the second session in which he practiced the game (first score: 3400, second score: 4600). Immediate evolution was also identified for the other two participants. For Participant 2 the first score obtained was 10.635, and the second score increased to 26.913. In the case of Participant 3 at the first use of the game he obtained a score of 8.740, and at the next use he managed to obtain a score of 15.700.

In addition to the immediate effect that the use of technology has had, there are also effects throughout this type of training, and the effects are seen in the improved scores as the training progresses. Thus, in the case of Participant 1 the starting score was 3.400, and at the end of this type of training he managed to achieve a score of 83.080. Participant 2 started from a score of 10.635 and achieved a score of 55.050 in the last training session involving technology. In the case of Participant 3, there are also large differences in the baseline point, which is the score obtained in the first session in which this type of training was used: 8.740 and the endpoint, which is the score obtained in the last session in which this type of training was used: 169.560. Therefore, based on the visual analysis of the data, it can be noticed the increase in the scores of the games used in the training involving technology and implicitly improvements in cognitive flexibility.

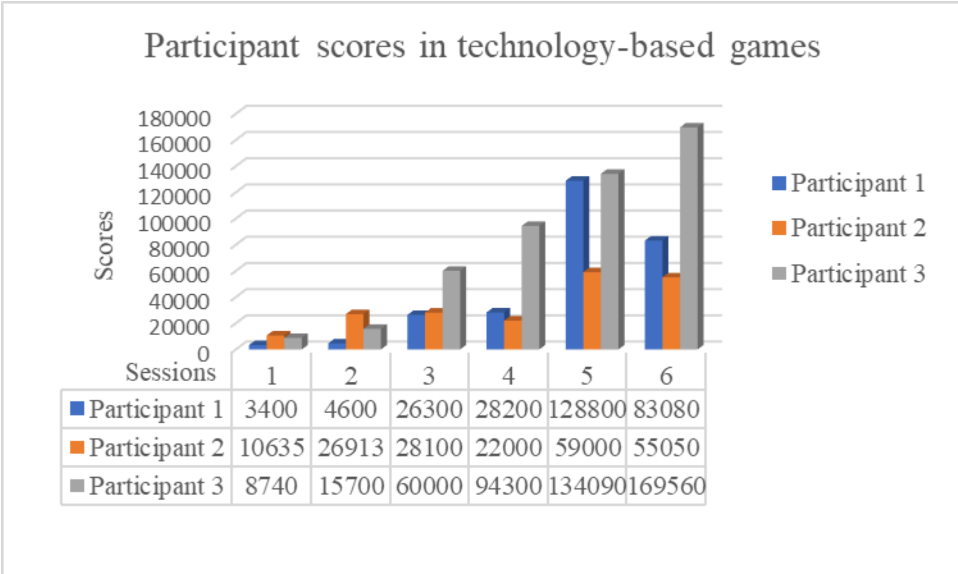

Figure 7. Participants scores in technology-based games.

10. Discussions

There is evidence in the literature of an increase level of engagement of individuals with ASD when interacting with technology, with interactions taking place in a safe environment. Recent studies have focused on the use of technology to teach skills to children with ASD. Thus, the possibility of training skills such as language skills, problem-solving, communication, social skills, and executive functions with technology has been noted. The results of a study by Wojciechowski, & Al-Musawi (2016) revealed that children with ASD were able to learn new words much faster when technology was used. Bernard-Opitz, Sriram, & Nakhoda-Sapuan (2001) emphasised that both typical children and children with ASD can learn certain problem-solving strategies via computers, in which there has been much more interest than in physical toys. As well, for children with ASD, involvement and motivation in activities can be increased through the application of technology (Measles, & Abu-Dawood, 2015). Similarly, Rashedi et al. (2021) reported that iPads helped the children to be calmer and more relaxed. Parents also reported that by using the technology, children were able to develop technical skills to obtain information on topics in which they were interested. At the same time, in the study we conducted, we observed that children showed much more interest in the technology-based intervention than in the non-technology-based intervention and were more motivated and eager to engage in the proposed activities.

More recent research has emphasised how deficits in executive functions can impact the school performance of children with ASD. It is considered a valuable aspect that impacts the developmental pathway of children with ASD on the ground that, contributes to access to independent living, higher education, and some employment opportunities when they reach adulthood (Vanegas, 2019). Baixauli et al. (2021) emphasised that children with ASD have difficulties in reading and decoding mechanisms of reading which are linked to reading comprehension process and cognitive flexibility. Pellicano et al. (2017) found that in 5- to 6-year-old children diagnosed with ASD, executive function skills predicted school readiness skills. Results of the study showed poorer performance on both EF and school readiness assessments in children with ASD, and differences in executive functions such as inhibitory control and working memory were associated with variations in academic performance.

Based on the studies and research being conducted in this field, a variety of compelling evidence can be noted that highlights the difficulties in cognitive flexibility within ASD. Deficits such as poor skills in adapting to novel contexts, in confronting and coping with obstacles, inflexible adherence to specific routines, difficulties in making transitions between different locations or events, restricted interests or excessive preoccupation with particular objects or activities, create a range of consequences across a number of developmental domains in children with autism. Cognitive flexibility is therefore a major executive function impaired in children diagnosed with autism. Thus, the identification of types of interventions and their subsequent application to test their effectiveness may produce beneficial outcomes for children with ASD, decreasing the difficulties associated with the low cognitive flexibility they experience.

The aim of this research was to test the effectiveness of a technology-based intervention in decreasing the number of errors in cognitive flexibility tasks in children with ASD. For Participant 1, there was no difference marked by a decrease in the number of mistakes because in the baseline phase the participant recorded a number of 115 points (errors) in the 6 sessions, while in the Intervention without technology the number of points (errors) increased to 132 points. However, if we look at the highest point on the graph in this phase which captures the last session of the baseline (33 points), we can notice that P1 managed to improve his performance on the cognitive flexibility task to some extent, reaching a number of 14 errors at the end of the intervention. In the case of the second participant, a big difference can be seen between the baseline level in which P2 achieved a number of 20 errors in all 6 sessions, and the Intervention without technology phase in which he only achieved two errors, the difference being a major one of 18 points. The results were similar for P3, who scored 59 points out of 6 sessions in the baseline phase, and the Intervention without technology phase, in which he scored 25 points out of 6 measurements (the difference was 34 points). Thus, the number of errors in the cognitive flexibility task was lower in the Intervention without technology phase compared to the baseline phase and for this participant. Thus, we noted that two of the three participants showed a decrease in the number of errors in the cognitive flexibility task in the Intervention without technology phase compared to the baseline phase. Thus, the first hypothesis was confirmed for two of the three participants.

Even though the technology-based intervention did not lead to improved outcomes compared to standard intervention, all three children showed improvements from baseline to the intervention phase. For the first participant, there was a difference of 18 points, with the number of errors in the baseline phase being 115 and, in the technology-based intervention phase, 97 points. For the second participant, the number of errors in the cognitive flexibility task was slightly lower in the technology intervention phase compared to the baseline phase, and this was captured based on a small difference, with the technology-based intervention scoring 13 points and the baseline phase scoring 20 points, thus showing a difference of 7 points. Participant 3 also showed a decrease in the number of errors in the cognitive flexibility task in the technology-based intervention phase compared to the baseline phase, P3 committed a total of 59 errors in the 6 sessions, whereas a decrease in the number of errors was evident in the Technology-Based Intervention phase, with P3 committing a total of 37 errors in the 6 sessions (difference of 22 points). Therefore, the second hypothesis was confirmed for all participants.

The lack of improved outcomes for the technology-based intervention compared to the standard intervention, despite all three children showing improvements in cognitive flexibility, could be due to several factors. First, both interventions may have targeted similar skills, resulting in comparable benefits and masking any distinct advantages of the technology-based approach. Another possibility is a ceiling effect, where the children had limited room for further growth or a short intervention duration that prevented the technology-based method from showing its full potential. Furthermore, individual differences in preferences and engagement could have influenced outcomes, as some children might respond better to human interaction or more traditional methods than to technology. Implementation challenges, such as technical issues or the way the technology was presented or implemented (on a mobile device), may have limited the effectiveness of the technology-based approach. These considerations suggest the need for longer-term studies, personalised approaches, and sensitive assessment tools to fully understand the potential benefits of technology-based interventions.

Within this research, we have identified a number of limitations to this research as follows. The small number of sessions in each phase. A larger number of sessions for both phases (baseline and intervention) could provide the possibility to determine in a more specific, precise, and targeted way the effectiveness of the two intervention models, which could be an aspect to be improved in future research. The chosen design (single-subject experiment) also has its limitations. In this sense, the small number of participants (three participants), limits the possibility of generalisability of the data, and the marked findings. We believe that similar research for a larger number of participants would provide more meaningful results and increase the generalisability of the data. Another limitation is the fact that we had a structured intervention protocol, future studies should propose and test the effectiveness of a more flexible intervention protocol.

Conclusion

Lately, research has been surprising and increasingly emphasising executive function deficits in children with neurodevelopmental disorders. Within ASD the main deficient executive function is considered to be cognitive flexibility. According to Diamond (2013b), cognitive flexibility includes the ability to think "outside the box", to look at something from several different perspectives or to change course when necessary, supporting creativity and theory of mind development. Impairments in cognitive flexibility have implications in most areas of development, which is why we believe that it is imperative to identify and test a series of interventions that are effective in training and improving cognitive flexibility. In children with ASD, there is a positive reaction to the gamification of tasks, which provides them with a secure environment. At the same time, the use of such tasks, as well as games in a concrete format can be useful points in the practical phase of intervention in the case of this executive function, even more so as they can involve a lower degree of anxiety, a higher degree of receptivity, creating a relaxing and effective atmosphere at the same time. Future studies should investigate different ways of involving technology in training executive functions in children with neurodevelopmental disorders.

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