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Antonyms: A Computer Game to Improve Inhibitory Control of Impulsivity in Children with Attention Deficit/Hyperactivity Disorder (ADHD)

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Abstract: The design of a computer-supported serious game concerning inhibition skills in children with Attention Deficit/Hyperactivity Disorder (ADHD) is reported. The game consists of a series of activities, each eliciting the tendency to respond in an immediate, inadequate way. The game is based on the Dual Pathway Model of ADHD proposed by Sonuga-Barke. In the game, children must block impulsive tendencies, reflect upon the situation, inhibit irrelevant thoughts, and find the non-intuitive solution. In the game, the player personifies a superhero, who is asked to save a realm on the opposite side of the Earth (Antonyms) where things happen according to the opposite of the usual rules. The hero faces a series of challenges, in the form of mini-games, to free the planet from enemies crossing different scenarios. To succeed in the game, the player should change his/her attitude by thinking before performing any action rather than acting on impulse. The player is induced to be reflective and thoughtful as well. Results from the evaluation of a preliminary version of the serious game are reported. They support the notion that Antonyms is an adequate tool to lead children to inhibit their tendency to behave impulsively.

Keywords: serious game; impulsivity; ADHD; inhibition; attention

1. Introduction

Serious Games (SGs) represent valuable tools in different fields of rehabilitation, due to the link between technology and flow, motivation, and sense of presence [1]. Their unique ability to attract, retain, and motivate players has prompted more and more teachers, psychologists, and educators to take advantage of SGs to help people to learn, grow, and face changes [2]. Besides, SGs, proposed as rehabilitation tools, can provide more responsive treatments or can increase the effectiveness of the therapeutic process [3]. Furthermore, SGs have proven to be effective in improving motivation, compliance with treatment [4–7], reading speed [8], executive functioning [9], planning and organizational skills, and, in general, the improvement of impaired skills [10]. SGs are able to promote behavioral changes in patients suffering from several illnesses [11–13] as well as impulse-related disorders, dysfunctional emotional regulatory processes, and disinhibited personality traits [14–17], which are among the most difficult core symptoms to address, even with well-established evidence-based psychological therapies [18,19]. Finally, several studies have supported the usefulness of SGs for enhancing positive attitudes [12,20], increasing problem-solving strategies,

and modifying abnormal behaviors such as those in children with Attention Deficit/Hyperactivity Disorder (ADHD) [12]. For instance, SGs could support the development of skills in visuospatial attention [21], which are lacking in ADHD patients.

Treating ADHD requires early intervention strategies to help children in all the deficient areas: working memory, suppression of inappropriate behaviors, inhibitory control, and shift between different activities [22]. Young people are often difficult to engage in treatment [23], which limits ADHD self-management into adulthood [24]. In addition, the persistence of the disorder in adolescence and adulthood is not matched by a continuity of care and treatment. Therefore, it is important to intervene during childhood [25] by enabling ADHD children to learn how to self-manage the impulsivity and inhibition to prevent the dysfunctional behaviors in adulthood [26,27].

ADHD patients get bored quickly, prefer immediate reward, and are usually motivated by the need to maintain the experience at a "minimum waiting level" [28]. Hence, it is important to constantly catch their attention: *gamification* (i.e., the application of game elements) can satisfy this requirement. SGs can help the child to stay focused and engaged the whole time, thus enhancing motivation and treatment effectiveness [29]. The same scenes and exercises can be repeated differently to prevent boredom and keep motivation high [30].

Several studies support the notion that SGs could help children, in particular those with ADHD, in improving attention abilities and executive functions [31]: e.g., CogMed©, a computerized training program [32]; PlayMancer (with the inclusion of biosignal data) [33]; Harvest Challenge BCI videogame, with the measurement of cerebral signals [34]; Virtual Classroom [35]; Plan-it Commander [36]; Boogies Academy; and Cuibrain [37]. Other studies highlight that SGs (e.g., Timo's Adventures [38]) could be useful to assess the abilities of young children with ADHD (cognitive function, reward mechanisms, and time perception). Some SGs include neurofeedback systems; It has been shown that these improve executive control in subjects with ADHD in combination with pharmacological treatment [39]. Other SGs use electroencephalogram (EEG) feedback to train attention ability [40]. In a pilot study, Lau et al. [41] investigated the effectiveness of a brain-computer interface (Braingame Brian [42]) in ADHD and found an increase in the ability to control inattentive symptoms and hyperactive-impulsive symptoms.

2. The Design of the SG

Not all SGs are useful for rehabilitation. Literature suggests three required components for the development of interventions based on SGs [43]. Firstly, interventions should be supported by current valid theories [44,45]. Secondly, interventions should be developed with the collaboration of the stakeholders [46]. Lastly, developers should account for the background in which the intervention is developed, considering the circumstances [47].

The SG presented in this paper has been developed focusing on these three main aspects. Firstly, the SG, called Antonyms, is based on a current valid theory: the Dual Pathway Model (DPM) proposed by Edmund Sonuga-Barke [48] to explain ADHD symptoms. The DPM considers two different developmental paths that identify ADHD: the cognitive pathway, related to inhibition and general executive dysfunction, and the motivational pathway, associated with delay aversion [48,49]. The first path is linked with activities that improve inhibition control and impulsivity control. The second path refers to activities that require a delay of reinforcement, thus it contrasts the tendency to choose an immediate smaller reward by making/constraining the subject waiting for a larger delayed reward.

The game was developed with the collaboration of children in order to include stakeholders [47], thus satisfying the second requirement. It focuses on the three main aspects of ADHD, namely inhibition—the ability to curb the behavior to allow the individual to continue and complete the task [31], impulsivity—hasty actions being taken without reflection, resulting from a desire for immediate reward or an inability to delay gratification [49], and cognitive flexibility—the ability to change one's mental perspective on the situation when needed [31].

The SG is designed for educational and rehabilitation settings to assess and train impulsivity, inhibition control, and cognitive flexibility in children aged 8–12. The aim is to either improve poor

inhibitory mechanisms in typically developing children or to habilitate such mechanisms in children with ADHD. The expected outcome is an increase in the ability to keep attention focused on the relevant elements of everyday life situations and to check the tendency to react without thoroughly analyzing the situation.

In Antonyms, the player personifies a superhero (called Atansyon), who is asked to save a realm on the opposite side of the Earth (Antonyms). Atansyon faces different steps, each represented by a mini-game, to free the planet from enemies passing through four scenarios: Woodland, River Crossing, Training School, and Central Building. The description of the main structure of three of the four scenarios (Woodland, Training School, and Central Building) of the SG is reported in Crepaldi et al. and Colombo et al. [50–52]. For this reason, the present paper only describes the fourth scenario (River Crossing) and the activities of the second level of difficulty for the Woodland and the Training School, not yet included in previous publications. Only some scenarios were tested because the development of the SG is still in progress.

The actions needed to complete the activities and scenarios included in the SG require self-control, planning skills, learning to delay impulsive responses, emotional self-regulation, reacting in a controlled way, paying attention to details, and increasing waiting time. The activities of the SG are based on the following grounds: the Flanker effect [53], the Stroop test [54], the Stop signal task, and the Conners' Continuous Performance test [55]. The Flanker task is composed of a set of tests to assess inhibition ability; It allows researchers to investigate the ability to suppress responses that are inappropriate in a given context [53]. The Stroop task consists of two different phases. In the first phase, participants are asked to read names of colors which are written independently of the color of the ink of the words. In the second phase, conflicting stimuli are presented: Participants are required to name the color of the ink of the letters of the words, which are presented independently of the meaning of the written words [54]. In the stop signal task (go/no go task), the subject must respond to an arrow stimulus, by selecting one of two options, depending on the direction in which the arrow points. The Conners' Continuous Performance test considers omission and commission errors and reaction time in selecting the right stimulus, which appears with intervals (ISIs) of 1, 2, and 4 s [55]. The mentioned tasks are usually employed to assess inhibition and impulsiveness. Our goal is not to reproduce these tests, but to use them as the gold standard to design a game that addresses the same variables.

Antonyms has been designed to be used in the presence of a therapist or an educator supervising the activities. Each mini-game has different levels of difficulty so that the tasks become more demanding and challenging as the user proceeds. It is worth mentioning the multi-modal, detailed, and immediate feedback provided by the games in the form of both visual and auditory messages. Moreover, it is possible to monitor the player's behavior during the game by recording the performance in the form of different types of error (e.g., errors in waiting and wrong answers) and completion time. All the results of the performances are saved immediately for each player and can be exported in an Excel workbook.

Antonyms is characterized by a narrative frame that engages players in all parts of the story. In this way, the response inhibition tasks are contextualized within the SG and the activation of inhibitory mechanisms is not arbitrary. Moreover, the SG is played from a first-person perspective to promote the sense of presence and the flow, two important elements for the achievement of the SG's goals. The activities refer to real-life tasks, even if presented in a fantasy world, to satisfy the third requirement for the development of SGs for interventions [47].

3. The Structure of the SG

Antonyms is designed to run on personal computers. The player interacts with the environments by touching the screen of the PC or laptop or using the keyboard [51]. At any moment in the game, it is possible to interrupt an activity and save the partial results. This is meant to give the child some time to reflect on the actions he/she carried out and on the strategies he/she applied with the therapist supervising the session.

The SG evolves in three main scenarios (Woodland, Training School, and Central Building) [50–52] and an additional scenario connecting the previous ones with each other (River Crossing).

3.1. Woodland (W)

W appears like a meadow covered with leaves. The first activity is focused on self-control, planning skills, and delaying impulsive responses. Briefly, the player must properly move the leaves to free the passage and to be able to proceed. Leaves must be moved from the most hidden to the external one, namely, the opposite of what people usually do. Children must stop the impulsive tendency to remove the most external leaf and are led to reflect on the best strategy to put into practice. The different sub-sections are characterized by different numbers of leaves: In the first sub-section, there are only two leaves, and then the number increases.

In the second level of W, the one that allows the passage from the Training School to the Central Building, the child is asked to do a more difficult task than in the first level. The player must move the leaves, as described before, to proceed along three more and more complicated paths, but he/she must also be careful to neutralize the poisonous leaves that will appear in front of him/her. These leaves should not be dragged, but avoided, trying not to get poisoned. Each step has a typical poisonous leaf that is shown to the player at the beginning of the path. The child has to keep it in mind and avoid touching it. If the player fails to do so, he/she has to restart from the last path concluded. The number of poisonous leaves increases with the passage from one path to another.

3.2. River Crossing (RC)

The player, after crossing the first part of the forest, faces open space with many rivers. RC is dangerous on this planet because bridges are often insecure and there is no way to understand which ones are dangerous and which are secure. Thus, each time the player encounters a bridge, he/she has to circumnavigate the river and take a longer route. This may seem counterproductive, but otherwise Atansyon would risk falling into the river and being left in wet clothes, which could cause, in turn, negative consequences.

Whenever the player is in front of a river, he/she can choose which road to take. The short one, which implies passing on the bridge, is faster but also dangerous (three safe and three unstable bridges have been included in the mini-game); By contrast, the longer route is safer. Depending on the choice he/she makes, the player will be brought to think about the possible consequences of the selected route.

3.3. Training School (TS)

TS looks like a normal school, but here all the guys are prepared to face the difficult challenges of the planet. The child has to pay attention (in the first activity, selective attention is stimulated) and not react impulsively to what happens. To overcome obstacles, adequate training of concentration and attention is needed, since the seemingly most obvious answers are often the wrong ones.

Two different activities were designed. The *first activity* takes place inside the school [51,52] and foresees a shelf, on which some objects useful to the mission appear. In the center of the screen, a target stimulus appears and the player must compare this stimulus with the object that appears on the shelf. If the objects are exactly the same, the player puts the object in the backpack, otherwise he/she puts it in the trash. Two different kinds of error are recorded by the system: the numbers of items different from the target which are placed in the backpack and the numbers of items identical to the target that are placed in the trash. The total number of errors is then obtained as the sum of the two kinds of errors. This total error score can be computed for each level of the activity. The time spent in completing the activity can be recorded as well. Inhibiting the impulse to immediately put the object either in the trash or in the backpack is fundamental to succeed, since the target stimulus and the object on the shelf differ only in subtle details.

The *second activity* is outside the school building, that is, in the garden of the school. In this garden, the player must pass several tests so as to reach the gate that leads to the forest (the second

level of W described above). The player has to collect "experience points" that will help him/her to get a better score at the end of the mission. The training course consists of hiding behind the bushes of the garden and trying to get to the flag placed at the bottom near the gate, without being discovered by the enemies. For this reason, the best tactic is to move from one bush to another every 2 s (the time can be increased to 3 or 5 s based on the child's ability). The ability to plan and consider possible consequences related to the actions is required. The score increases every time the child makes a correct move. Each error entails the return to a previous bush and is counted as an error.

3.4. Central Building (CB)

CB is the last scenario of the SG. The main task consists in crossing a dark corridor to reach the control room of the building; The player can move forward only in predefined steps, by clicking/tapping on a light signal appearing on the floor. Two paths differing in direction and predictability are possible. One is characterized by less abrupt movements, whereas the other one includes more changes in direction, making it more difficult for children. Each path has two levels of difficulty. In each level, the player picks out 57 lights that appear on the floor and 49 movements to proceed are available. The sequence of the lights is statistically controlled according to the structure of the timing in the Conner's Continuous Performance test [55]: the light will turn on 1, 2, or 4 s after the previous one.

In the *first level of each path*, the player is asked to pay attention only when he/she turns the green light to move. In the *second level of each path*, the player will find eight blue lights, displayed at random time intervals, that he/she must not touch. The player has to control the tendency to click or touch these lights. This structure allows trainers to evaluate different types of error. Position errors are counted when the green light appears and the player clicks in a different location; omission errors, when the green light is on (it stays on for 3 s) but the player does not click; impulsivity errors, when selecting the wrong color, e.g., the player clicks on the blue light instead of waiting for the green one; and anticipation errors, when the player clicks before any light appears.

The tour ends with arrival in the control room of the building. The final score is computed based on the degree of impulsiveness shown by the player: five points for a correct answer in less than 1 s, ten points for such an answer in 1 to 3 s.

4. Applications of the SG: Preliminary Results

All the parts of Antonyms were designed also based on the opinions of children, collected through an ad-hoc questionnaire [50] filled out after playing the SG. These feedbacks led the designers to modify the SG accordingly. Three parts of different scenarios have been completed and tested with children.

The first experiences with the SG supported the effectiveness, usability, and ergonomics of the SG [51,52]. Later [50], the SG was proposed to 30 typically developing children (16 boys; age: M = 9.30 yrs., SD = 0.87) attending the 3rd, 4th, and 5th grades of primary school. Each child was engaged in playing the TS and CB sections of Antonyms in individual sessions of 45 min. The overall message that emerged was that the scores children obtained in Antonyms were positively correlated to scores in standardized clinical measures of inhibition. Therefore, there is evidence that the activities embedded in Antonyms appeared to be associated with performance in standard tests usually employed to assess inattention, impulsivity, and hyperactivity levels in ADHD.

5. Performance in the SG by ADHD Children vs. Controls

Starting from the results obtained in the study with healthy participants [50], we decided to conduct a further study to a) compare the performances in the SG of a small group of ADHD children with that of a group of typical children of the same size, matched for age and gender; and b) confirm the correlation patterns, found in the previous study [50], between SG scores and standardized measures of sustained attention, inhibition, and interference control in a group of children with and without ADHD.

5.1. Materials and Methods

5.1.1. Participants

Antonyms was proposed to 16 boys aged 8–11 (M = 9.19 yrs.; SD = 0.91). The sample included 8 children who had received a diagnosis of ADHD prior to enrollment in the study and 8 children without ADHD or any other neurodevelopmental disorder. Participants were recruited from the same geographical and cultural areas. The two groups (i.e., ADHD and controls) were matched for age ($U_{(1)}$ = 28; p = 0.70) and gender (only boys were recruited).

5.1.2. Procedure

Children underwent two individual testing sessions of 45 min each, which took place in a quiet room of the school in which they were recruited. Participation was voluntary with the permission of parents. A psychologist welcomed the child, told the story constituting the narrative background of the SG, and explained the instructions of the SG. The psychologist sat down near the child so to answer possible questions and to assist him/her if any problem occurred. Two standardized tests from the BIA [56], usually applied to diagnose ADHD, were administered before the SG: the Ranette and Number Stroop tests.

The first test, *Ranette*, requires patching the frog whenever a certain sound is presented ("GO" sound) and to stop when another sound appears ("STOP" sound). The test involves sustained attention (the test lasts about 10 min), selective attention (children must select the target sound), and motor inhibition (children must block the impulsive response to go ahead).

The second test, *Number Stroop*, involves the presentation of stimuli eliciting two alternatives and incompatible responses, one of which (the one you should not give) is more spontaneous than the other one (which you must give) because it is automated. The test consists of two parts: the baseline task, in which individuals are asked to count how many asterisks are present in each box, and the Stroop task, in which the request is to count how many elements (numbers) are present in each cell. This test measures interference control and inhibition, considering interfering errors.

5.1.3. Results

Due to the small sample size, non-parametric statistics were used (Mann-Whitney U test for independent samples and Spearman's rank correlations, one-tailed). Descriptive statistics of the BIA scores in each group are reported in Table 1, along with the BIA scores from the sample of typical children who took part in the preliminary study [50]. As expected, the control group (N = 8) which was paired to the ADHD group showed scores very similar to the larger sample of typical children (N = 30) of the previous study.

Table 1. BIA Scores in a) typical children from the Crepaldi et al. (under review) study, b) the paired control group, and c) the clinical group of ADHD children from the study reported in this article.

Tests	Controls (N = 30)		Paired Controls (N = 8)		ADHD (N = 8)	
	Mean	SD	Mean	SD	Mean	SD
Ranette-errors	1.93	1.76	1.63	0.52	5.50	2.20
Stroop-errors	2.18	1.61	2.25	0.71	4.13	3.83

As for the standardized tests, ADHD children showed lower performances in the Ranette subtest of the BIA battery, compared to the control group ($U_{(1)}$ = 2.50; $p < 0.001$; d = 2.42). The same trend emerged for the Number Stroop test, but the difference between groups did not reach statistical significance ($U_{(1)}$ = 31.50; p = 0.50).

The performance in both SG activities was found to be significantly different between groups, with the ADHD group scoring lower (see Table 2). More precisely, ADHD children made a greater

number of Trash Errors in the TS activity ($U_{(1)}$ = 10.00; p = 0.01; d = 1.44) as compared to controls. Furthermore, ADHD children made a greater number of Position Errors in the CB activity ($U_{(1)}$ = 14.50; p = 0.03; d = 0.87).

Table 2. Training School (TS) and Central Building (CB) scores in the ADHD groups vs. the control group. Differences were tested using the Mann-Whitney U test, one-tailed. Alpha = 0.05 (statistical significance is marked in bold).

Antonyms Activities	Paired Controls (N = 8)		ADHD (N = 8)		Comparison
	Mean	SD	Mean	SD	$U_{(1)}$, p
TS Total errors	8.38	5.53	13.25	3.96	13.0, 0.02
TS Trash errors	2.38	1.51	6.38	3.62	10.0, 0.01
TS Backpack errors	6.00	4.72	6.88	3.72	25.0, 0.25
CB Total Errors	7.50	5.71	11.25	5.97	17.5, 0.64
CB Omission errors	4.25	3.24	4.25	1.58	30.0, 0.44
CB Impulsivity errors	0.00	0.00	0.25	0.71	28.0, 0.19
CB Anticipation errors	1.50	1.77	1.75	2.91	30.0, 0.61
CB Position errors	1.75	2.25	5.00	4.78	**14.5, 0.03**

Correlation patterns, considering the entire sample, revealed associations between the SG scores and the standardized measures of inhibition, sustained attention, and interference control. The Backpack Errors in the TS correlated positively with Stroop errors (rho = 0.59; p = 0.01). On the other hand, the Trash Errors in the TS correlated positively with the number of errors in the Ranette task (rho = 0.59; p = 0.01). Finally, the total number of errors in CB was found to be positively correlated with the number of errors in the Ranette task (rho = 0.44; p = 0.04).

6. Conclusions

SGs could be useful tools in rehabilitation because they allow therapists to provide stable and controlled stimuli concerning children's progress, constantly checking feedback. Furthermore, they offer flexibility and provide safe learning environments that minimize errors, time, and costs. Finally, SGs keep users motivated through pleasant and user-friendly environments [57]. From this perspective, Antonyms represents a promising tool to target impulsivity control because it is grounded on a neuropsychological evidence-based model focused on impulsivity, a personal feature that needs a cognitive mechanism (inhibition) to be managed properly, thus prompting self-regulation and stimulating metacognition thanks to a reflective attitude.

Data collected with children without ADHD revealed that performances in Antonyms correlate with scores in the standard tests administered to diagnose ADHD, which refer to the same dimensions (inhibition and impulsivity control) that are targeted by the SG. The same finding has been detected in another study on a different sample, which includes, again, both children with and without ADHD, whose performances in the SG correlated with scores in standard ADHD tests. In particular, the number of errors in the Ranette subtest of the BIA was related to errors in TS and CB. Furthermore, children with ADHD obtained lower performances in Antonyms than typically developing children of the same age and belonging to the same socio-cultural level: the errors committed by ADHD children were more than the ones performed by children without ADHD. These findings indirectly support the potential to use Antonyms as a tool in assessment and rehabilitation programs. In the future, all the designed mini-games should be implemented in order to test the efficacy of Antonyms and to propose the SG to larger samples of children with ADHD as a training tool to also verify its efficacy as a rehabilitative instrument.

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