# The Role of a Virtual Avatar in Attention and Memory Tasks in Rett Syndrome

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# Abstract

**Background:** Since subjects with Rett syndrome (RTT) focus their attention mainly on the faces of people with whom they interact, in this study the role of a human-like avatar in enhancing cognitive processes was examined. More in depth, this study examined subjects with RTT performing attention and memory tasks with and without a virtual avatar.

**Method:** Thirty-six girls with RTT participated in the study. They were matched for mental age and randomly submitted to two conditions (with and without virtual avatar) with two tasks (over-selectivity and memory paradigms).

**Results:** The results indicated that the RTT group exposed to the virtual avatar condition, presented better attention and memory abilities than the matched RTT group without the avatar condition.

**Discussion:** The results were discussed in light of the relationship between motivation, attention and memory in RTT.

# Background

Rett syndrome (RTT) is a complex genetic disorder, caused by mutations in the X-linked gene encoding for a regulator of epigenetic gene expression, methyl CpG binding protein (MeCP2). The clinical picture of RTT is defined by loss of hand use and language, with the development of gait abnormalities and hand stereotypies[1-4]. Because of the specific characteristics of the syndrome, subjects with RTT often use their eyes to communicate[5-7].

New promising approaches have recently shown that technology-aided programs for subjects with severe/profound and multiple disabilities are useful in enabling performance of daily tasks and improving cognitive abilities[8]. Spaghero[9], in a study exploring virtual reality, demonstrated that subjects with intellectual disabilities can present a marked improvement in attention when interacting with virtual bjects and events. Therefore, this new approach has been recognized, as it provides a safe environment in which any individual can enjoy pleasurable activities, music[10] and communicating with the family[11]. Another major advantage in using technology-aided interventions is the possibility to acquire huge amounts of data, essential for advanced data analysis such as predictive analysis[12].

A new trend in current technologies is the presentation of a virtual environment to subjects through an avatar that gives positive feedback to the subjects on the correction completion of a task, thereby improving motivation[13-16]. Avatars, i.e., graphical characters able to show human-like facial expressions and gestures, to speak and even react to users' interaction by interpreting gestures, emotional states and speech, have been exploited for several applications in the past[17]. Furthermore, virtual environments have often been combined with advanced human-computer interaction (HCI) technologies to facilitate user interaction in complex tasks[18].

The use of avatars has been shown to be effective in increasing attention in various disabilities[19, 20], however, it has not yet been explored for people with RTT. In the study by Mantziou, Vrellis, Tassos, and Mikropoulus[21] the possibility of recognizing emotions in subjects with autism was investigated, by means of an avatar, able to recreate facial expressions inherent to specific emotions. Further evidence was provided by experimenting with an avatar[22, 23] in Attention Deficit/Hyperactivity Disorder (ADHD)[24-27]. These studies suggest that an avatar can be used as a computerized pedagogical agent with realistic characteristics; for example, it can appear on a computer screen and guide users through multimedia learning environments, designed to support learning and direct attention to relevant topics. In the study by Mohammadhasani[22], a virtual avatar similar to a young male nerd was created for teaching ADHD subjects, it provided options for solving mathematic and logic problems. Results of this study suggested that it could be possible to elicit greater attention in subjects with ADHD and highlight how the presence of a pedagogical agent may improve the performance of subjects.

The role of a pedagogical agent is also supported by other theories. One of these is Computers Are Social Actors (CASA); according to this theory, humans tend to respond to the media in the same way they would respond to humans, so the avatar would become a real social model[29]. A theory developed by Wang, Wenjing and Heping[30] also states that people would learn better from multimedia presentations in the presence of a pedagogical agent, recognizing social presence. For these reasons the use of the avatar becomes effective for students to structure the appropriate processes and improve attention and learning[31] strengthening their interests[32].

Other evidences on the role of the virtual avatar were provided by a study by Fabio, Caprı, Iannizzotto, Nucita and Mohammadhasani[20] in which subjects with ADHD underwent three experimental conditions. In the first condition, the avatar simply provided instructions; in the second condition the avatar presented the instructions and also provided feedback on the student's attention; in the third condition the avatar was not presented. Results showed that the presence of the virtual avatar increased the problem-solving ability of the subjects. These benefits were also confirmed in the work of Shema-Shiratzky, Brozgol CornejoThumm[33].  Summarizing, avatars showing behaviours that the users feel as familiar[35] can become real tutors, coaches, motivators, mentors, models to emulate[34].

This study aims to examine whether the use of an avatar can improve motivation and, subsequently, attention and memory processes in girls with RTT. The tasks were implemented through eye tracking technology. The underlying logic is that the motivation process significantly affects some cognitive functions, such as attention and memory. Since girls with RTT are very motivated to look at the face of therapists and parents, an avatar acting human-like gestures, speech, gaze and behaviors may be very motivating to join with the in the learning process.

Attention and memory tasks were presented with two conditions.In the first condition, the avatar gave the instructions and asked the patient to give the answer. In the second condition there was no avatar. A voice gave the instruction and solicited the replies. The hypothesis was open: on one hand it may be that the avatar, acting as a social motivational model[29]can induce girls with RTT to focus and memorize more efficiently; on the other hand, based on the redundancy theory of Mayer[28], since the avatar is a third element it may be that it acts like a distractor and, not necessarily improve attention and memory.

Furthermore, since the eye tracking methodology helps to distinguish the encoding phase (with the registration of the length of fixations) and the retrieval phases (with the number of items recalled), in this study we want to understand if the avatar is effective in the encoding phase or in the retrieval phase or both. As shown in previous studies with ADHD children[24-27] we expect that, if the subjects with RTT show a high level of length of fixation in the condition with the avatar, such a condition will produce benefits also in the retrieval phase.

# Method

### Participants

Forty-one subjects with a diagnosis of RTT took part in the experiment. Forty were female and one was male. Their families had been contacted by the Italian association for Rett syndrome (AIRETT)that asked them to participate in the study. The families come from all over Italy. Five subjects were excluded from the study since they were not able to focus on the stimuli of the monitor. For this reason, finally, 36 subjects participated in the study. They ranged in age between 4 - 32 years. A general assessment was carried out by a psychologist through the Vineland Adaptive Behaviour Scale (VABS)[36] and the Rett Syndrome Rating Scale (RARS)[37]. Thirty-one girls and one male attended schools or socio-educational centres; four girls were assisted by an educator at home. All showed little or no purposeful hand use and pervasive hand stereotypies were striking. Ambulation was preserved in 19 girls. Table 1 shows the chronological age of the participants, the RARS scores as well as the VABS Scores.

### Material

A Tobii Series-I eye-tracker was used to record the subject's visual scanning. This device records ocular movements such as the location and duration of ocular fixations (pause of eye movement on an object of interest) and saccadic movements (rapid movements between fixations). The participant was positioned at a distance of about 30 cm from the screen and the direction of the gaze was determined according to the Pupil Centre/Corneal Reflection Method in low-intensity infrared light. Passive gaze tracing (LC Technologies, Sao Paulo, Brazil) software was used to generate gaze data during visuals scanning. In addition, this device allows to define the areas of interest (AOI) within the images chosen for the statistical analysis of eye tracking. An AOI cluster refers to selected specific areas that are used for both attention and recalling details of the images.

The eye-tracker was used for both the overselectivity paradigm and the memory paradigm. The avatar was created using an educational platform "Voki for Education" (https://www.voki.com/). Voki is a free collection of customizable speaking avatars for teachers and educators that allows users to create a precise profile of a talking character. Voki is created by Oddcast and can be customized to look like humans, cartoons, and/or animals.

The characteristics selected for the creation of the avatar were chosen through a pre-calibration, carried out during the 2018 Airett Campus in which several subjects with RTT spent their holidays with family and educators. The pre-calibration was fundamental as it allowed to include the avatar that the RTT subjects prefer. Following, the materials of both paradigms will be presented.

### Memory paradigm

The memory test was implemented. The story-cartoon presented with Tobii eye-tracker was easy to understand and remember, and the descriptions of facts were presented in a logical order. The cartoon sequences were extracted from “La Pimpa” and they were: “ant Bibi” and “Pimpa on the beach”. They were chosen out of seven cartoon sequences presented to 31 3-year-old children and calibrated on the basis of their comprehension of the story (> 90%) and on the basis of their recalling indices (>90%).The questions have various levels of difficulty, from simple recognition of the main character of the story, to recognition of the emotional states of the characters, to identification of the actions within the story.

Each cartoon sequence contained 8 significant memory indices (Table 2). Both cartoon sequences “Ant Bibi” and “Pimpa on the Beach” lasted 2:30 minutes.

The test was carried out for each patient. After each cartoon was presented through the eye-tracker, the participants were asked to perform immediate recall of the cartoon with a recognition test with 8 questions regarding the story (Table 3).

For each of the relevant indexes two cards were presented on the screen, the correct answer and the distractor answer (Figure 1). The scoring standard used in the present study involved giving 1 point for choosing the correct answer, and 0 point for choosing the distractor.

### Overselectivity paradigm

In this paradigm, 2 cards of 10 cm x 30 cm, each one reporting a different complex stimulus composed of three familiar objects shown in black and white, were presented on the screen of the Tobii eye-tracker. In the second phase, individual stimuli, consisting of cards of about 10 cm x 10 cm, were presented on the screen. Each card represented a single familiar object previously included in the target complex stimulus (Figure 2). The cards were calibrated in a previous study[38]. In the condition with virtual avatar, the avatar presented both the complex stimuli and the individual stimuli between which the participant had to choose (figure 3, phase 1 and 2). In the condition without virtual avatar, no avatar was presented to participants.

### Procedure

The experiment was carried out in a quiet room during the 2019 Rett summer campus of the AIRETT. The examiner administered the VABS and the RARS through an interview with the parents of the subjects with RTT and the educators. Participants sat in a dimly lit room of the association in front of the eye-tracker screen at a distance of 30 cm. The eye tracker was positioned in such a way that ambient lighting did not affect the recordings. The eye tracking equipment was calibrated for each participant at the beginning of the experiment. Gaze fixations of at least 1000 ms within a region of 2°– 3° around each calibration point were considered accurate. The two tasks of this experiment were presented randomly in two conditions with and without avatar, as given in table 4 and 5.

### Measures

Memory task: fixation length (FL) of the correct stimuli related to the significant memory indices during the vision of the cartoon and the number of the recalled correct indexes. FL refers to the amount of time (seconds) spent by the subject when looking at the correct stimulus. Total fixation length refers to the sum of the time spent in looking at each significant index during the vision of the cartoon. Fixations were extracted using a threshold of 100 ms.

Overselectivity task: FL of the complex correct stimulus and the number of the individual correct recalled images

### Statistical analyses

The data were analysed using SPSS version 22.0 for Mac. The descriptive statistics of the dependent variables were tabulated and examined. Alpha level was set to 0.05 for all statistical tests. In the case of significant effects, the effect size of the test was reported. The relationship between continuous variables was evaluated by determining Pearson’s r; group comparisons were conducted using t-test for paired samples.

## Results

With reference to the memory paradigm, a preliminary analysis showed that the two cartoons “Ant Bibi” and “Pimpa on the Beach” showed no statistical differences either with reference to fixation length of the total correct stimuli ($t(35)=1.1$, $p=.43$) or the number of the correct recalled indexes ($t(35)=0.76$, $p=.67$); for this reason in the following statistical analysis the mean of indexes of both cartoons is used. Table 6 shows means and standard deviations of the two conditions.

With reference to the length of the total correct stimuli results show significant differences, $t(34) = 4.55$, $p<0001$. This means that the time spent in looking at each significant index during the vision of the cartoon was higher when the avatar helped the subjects than when the avatar was not present. With reference to the number of the recalled correct indexes, results show significant differences, $t(29) = 6.02$, $p<.0001$. Subjects with RTT recall more significant indexes when the avatar is present than when it is absent.

With reference to the overselectivity paradigm, table 7 shows means and standard deviations of the two conditions.

Regarding FL of the complex correct stimulus, results show significant differences, t (35) = 6.61, p<.001. This means that the time spent in looking at the correct complex stimulus was higher when the avatar was present than when the avatar was not present. With reference to the number of the individual correct recalled images, again results show significant differences, t (29) = 7.01, p<.0001. Subjects with RTT recall more significant indexes when the avatar is present than when it is absent.

With reference to the second question here addressed, the avatar helps both encoding and retrieval phases. Pearson's coefficient r was chosen as the measure of the strength of correlation. With reference to the memory paradigm the relationship between FL of the correct stimuli related to the significant memory indexes during the vision of the cartoon and the number of the recalled correct indexes is very high, r (35) =. 678, p<.001. With reference to the overselectivity task, the relationship between FL of the complex correct stimulus and the number of the individual correct recalled images is high, r (35) = .52, p<.001.

# Discussion

In this study the first question addressed was if the avatar can act as a social motivational model[29]and improve attention and memory or if it is redundant [28]acting like a distractor and disrupting attention and memory. Both results, related to the two paradigms here analysed show that the avatar acts as a cognitive strengthener. The second question here addressed is if both phases (encoding and recalling) were empowered through the avatar. Results indicate that subjects with RTT show a high level of length of fixation in the condition with the avatar and this produces benefits also in the retrieval phase.

Our results support the role of the avatar in learning environments and emphasizes the social aspect in the attention process. These results are in line with the CASA theory. According to this theory, humans tend to respond to the media in the same way they would respond to humans, so the avatar could become a real social model[29]. Wang's theory also states that people would learn better from multimedia programs on the screen in the presence of a pedagogical agent, recognizing social presence[30]. For these reasons, the use of the avatar becomes effective for subjects with RTT, to structure the appropriate processes and improve their attention and their learning[31, 39-45].

In line with this[46-48], our avatar not only gives instructions on the relevant aspects of the coding phase but also helps the subjects to better recall the contents. Hence, our results indicate that an interactive avatar that helps subjects with RTT to better direct their attention can concretely improve cognitive performance. We consider the findings reported in this article a relevant contribution to the introduction of a new generation of embodied interactive virtual agents (interactive avatars) aimed at supporting subjects with RTT in their everyday activities[49, 50]. These findings can help families and educators to identify what sort of software can be effectively used to help subjects with RTT, and also software designers to make good evidence-based choices to offer more focused software, capable of giving significant performance improvements[51-58].

A limitation of this research is that the graphical, behavioural, and technological characteristics of the avatar were not discussed. It might be argued that they can influence the effectiveness of the avatar in improving the performance of subjects with RTT. Another limitation of this study may also be related to the size of the sample. In this study, the sample size is small and there may be constraints to the generalizability of the results. However, the effect size is adequate; consequently, the results from groups can be considered reliable. Future research is needed to understand the conditions under which an avatar can enhance learning abilities and learning process.

# Abbreviations

ADHD: Attention Deficit Hyperactivity Disorder

AIRETT: Italian association for Rett syndrome

CASA: Computers Are Social Actors

FL: fixation length

RTT: Rett Syndrome

VABS:Vineland Adaptive Behaviour Scale

RARS: Rett Syndrome Rating Scale

# Declarations

## Authors’ contributions

RAF and GP designed the study. RAF and GP recruited the participants. TC diagnosed the participants. TC and GP assessed the participant with the experimental tasks. RAF, AN and GI analysed the data, RAF, GP, AN, GI and TC wrote the manuscript. All authors read and approved the final manuscript

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## Availability of data and materials

All data generated or analysed during this study are avalaible under request.

### Ethics approval and consent to participate

The study was conducted in accordance with the American Psychological Association's (APA) ethical standards. The study design was approved by the Human Ethics Committee of Cognitive Science, Psychological, Educational and Cultural Studies of the University of Messina approved the study

protocol (Protocol n. 20015_36). All the parents of the children who took part in the study signed a written consent form.

### Consent for publication

Not applicable.

### Competing interests

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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# Tables

Table 1

Descriptive characteristics of the patients with Rett Syndrome

| | Name | Clinical stage | Age | MeCP2 Mutation | RARS¹ Point score | Level1 of severity | VABS² score |
|---|---|---|---|---|---|---|---|
| 1 | A.L.R. | III | 13 | c.1063-1326 del264+insTGCG | 63,5 | Moderate | 110 |
| 2 | A.C. | IV | 36 | T158M | 59 | Moderate | 63 |
| 3 | A.S. | III | 13 | c.1566_1197 del41 | 76,5 | Moderate | 92 |
| 4 | S.B. | III | 12 | c.916C>T | 69 | Moderate | 88 |
| 5 | D.O. | IV | 29 | R255C | 72 | Moderate | 86 |
| 6 | G.V. | III | 8 | / | 48,5 | Mild | 121 |
| 7 | S.B. | IV | 31 | R255C | 59,5 | Moderate | 165 |
| 8 | S.C. | III | 16 | T158M | 71 | Moderate | 92 |
| 9 | A.I. | III | 22 | c.1164-1189 de 26 | 66,5 | Moderate | 84 |
| 10 | M.M. | II | 4 | C.916C>T | 66,5 | Moderate | 83 |
| 11 | A.B. | III | 11 | R255X | 66 | Moderate | 83 |
| 12 | G.T. | III | 14 | / | 56 | Moderate | 58 |
| 13 | K.C. | II | 4 | c.763 C>T | 80,5 | severe | 40 |
| 14 | C.A. | II | 4 | PT158M | 52,5 | Moderate | 60 |
| 15 | M.M. | III | 26 | R270X | 56,5 | Moderate | 65 |
| 16 | V.A. | III | 5 | R294X | 66,5 | Moderate | 80 |
| 17 | E.M. | III | 14 | R270X | 61,5 | Moderate | 76 |
| 18 | E.P. | IV | 29 | P.R135C | 39 | Mild | 168 |
| 19 | M.L. | III | 5 | p.Pro322Leu | 58,5 | Moderate | 75 |
| 20 | C.T. | III | 7 | / | 47,5 | Moderate | 60 |
| 21 | A.M. | III | 20 | CDLK5 | 61 | Moderate | 56 |
| 22 | S.L. | III | 8 | p.R133C | 35 | Mild | 140 |
| 23 | L.G. | III | 10 | FOXG1 | 86,5 | severe | 35 |
| 24 | M.G. | III | 17 | arg168stop | 37 | Mild | 121 |
| 25 | V.A. | IV | 35 | / | 47 | Mild | 118 |
| 26 | G.S. | II | 4 | C.916C>T | 74 | Moderate | 50 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 27 | A.L. | III | 10 | T158M | 81 | Severe | 33 |
| 28 | A.C. | II | 4 | 71,5 | Moderate | 56 | |
| 29 | S.P. | III | 16 | 168RX | 62 | Moderate | 131 |
| 30 | R.E. | III | 18 | / | 67,5 | Moderate | 107 |
| 31 | V.A. | III | 7 | R168X | 51,5 | Moderate | 82 |
| 32 | D.C.N. | III | 12 | R306C | 59 | Moderate | 84 |
| 33 | V.S | III | 16 | R133C | 64,5 | Moderate | 110 |
| 34 | Z.F | III | 14 | P322A | 52,5 | Moderate | 86 |
| 35 | G.S. | III | 19 | R255C | 74,5 | Moderate | 84 |
| 36 | D.G. (male) | III | 20 | c.964 C>T | 58,7 | Moderate | 105 |

Table 2

Significant indexes of cartoon sequence

| | |
|---|---|
| Ant Bibi | Pimpa on the Beach |
| Main character | Main character |
| Secondary character | Action of Pimpa |
| Colour of main character | Secondary character |
| Ant character | Action on the beach |
| Action of Pimpa | Emotions of Pimpa |
| Underground | Crayfish character |
| Emotions of Pimpa | Underground |
| Final action | Final action |

Table 3

Questions related to the significant indexes of the cartoon sequence

| Ant Bibi | Pimpa on the Beach |
|---|---|
| 1.Who was the main character of the story? | 1. Who was the main character from the story? |
| 2. Who met Pimpa at the beginning of the story? | 2. What was Pimpa doing? |
| 3. What colour was Pimpa? | 3. Did Armando want to play with Pimpa? |
| 4. Who met Pimpa? | 4. Who did Pimpa play with on the beach? |
| 5. What was Pimpa taking, the sack or the bucket? | 5. Was Pimpa sad or happy? |
| 6. Were there clouds or stars? | 6. Who did you meet after the Pimpa? |
| 7. How happy or sad was Pimpa? | 7. Were there sun or stars? |
| 8. What did Pimpa do at the end of the story? | 8. What did Pimpa do in the end? |

Table 4

Memory task procedure

| Experimental condition | Procedure |
|---|---|
| With avatar<br><br>Without avatar | The avatar appeared initially on the whole screen of the Tobii I-15 and said "Hi, my name is Giorgio. Watch this cartoon with me!"<br><br>Then the avatar became smaller and moved to the lower left part of the screen. During the cartoon, it only moves its eyes and head in a stereotyped way to make the avatar seem alive.<br><br>After watching the first cartoon, the avatar appeared again and says "Hello, we will play together now!”<br><br>Then the avatar started by asking the participant the 8 questions. Participants had to choose the correct answer with their eyes and avoid focusing on the distractor.<br><br>Then the avatar appeared again and repeated the process with a second video.<br><br>No avatar was presented to participants. The story-cartoon presented with Tobii eye-tracker. |

Table 5

Overselectivity paradigm procedure

| Experimental condition | Procedure |
|---|---|
| Without avatar | In the first phase, two images, placed 40 cm from each other, reporting complex stimuli (ABC, correct stimulus; XYZ, incorrect stimulus (Figure 2) were presented. |
| With avatar | The examiner presented each subject with the correct complex stimulus described as the “correct one”; both the correct and incorrect cards were then presented on the screen in front of each subject who was subsequently asked: “Which is the correct one?”<br><br>Forty-five seconds were allowed to answer the question. The subjects could answer by grasping an image or by looking at it.<br><br>If the subject chose the correct card (ABC) during the 45 sec, the examiner gave them a verbal reinforcement (e.g. "Great!" “Very good!”). If the subject chose the incorrect image (XYZ) or did not choose any image during 45 sec, both were removed, and the ‘no’ answer was coded, and a new possibility of choice started after 10 seconds.<br><br>In the second phase, the examiner used the cards reporting individual objects extracted both by correct and incorrect complex stimuli by devising 9 different pairs of individual stimuli from the combination of A with Y, B with X etc. The examiner asked every participant to choose the correct stimulus.<br><br>The avatar presented both the complex stimuli and the individual stimuli between which the participant had to choose (phase 1 and 2). |

Table 6

Means and Standard deviations of the parameters of the memory task

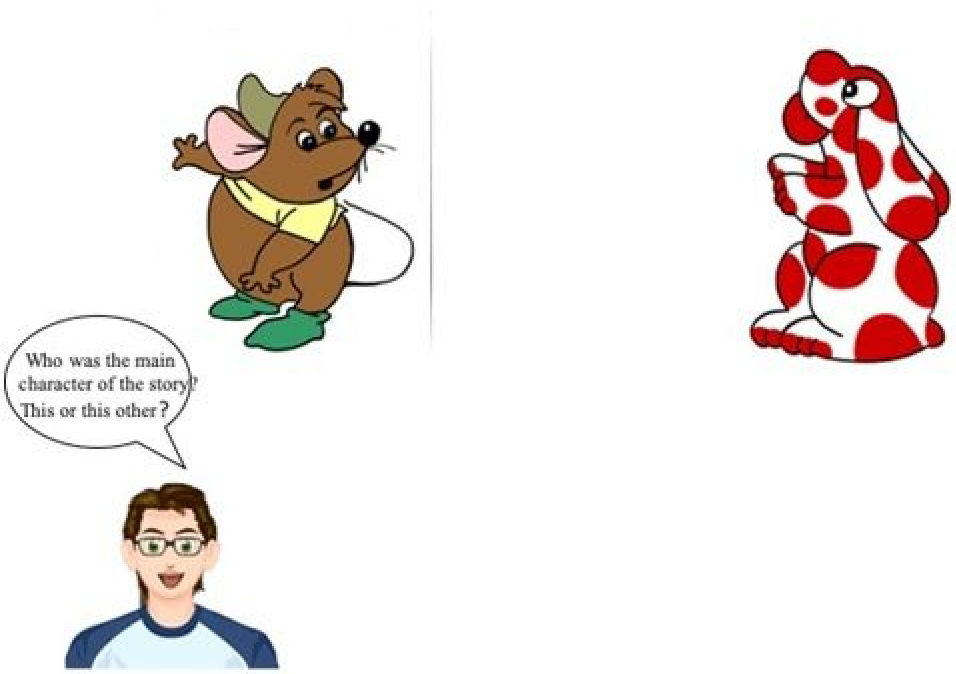
| Conditions | Mean (standard deviation) |
|---|---|
| With Avatar | |
| fixation length of the total correct stimuli | 26.37 (12.95) |
| number of the recalled correct indexes | 5.23 (1.10) |
| Without Avatar | |
| fixation length of the total correct stimuli | 15.95 (11.82) |
| number of the recalled correct indexes | 3.23 (1.99) |

Table7

Means and Standard deviations of the parameters of the overselectivity task

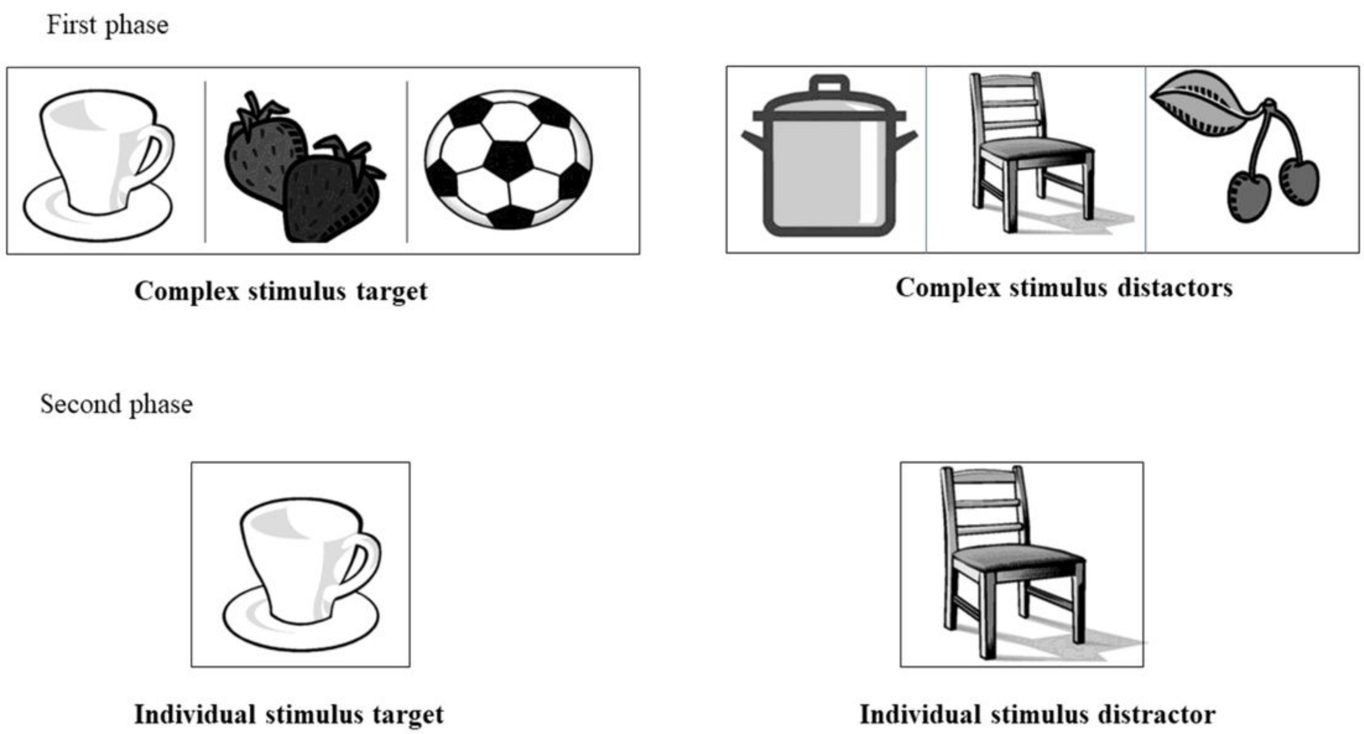
| Conditions | Mean (Standard deviation) |
|---|---|
| With Avatar | |
| fixation of the complex correct stimuli | 28.51 (9.22) |
| number of correct individual stimuli recalled | 6.19(2.33) |
| Without Avatar | |
| fixation of the complex correct stimuli | 18.32(11.01) |
| number of the recalled correct indexes | 3.72(0.99) |

# Figures




### Figure 1

Recognition test: target and distractor




## Figure 2

Overselectivity stimuli


## Figure 3

Recognition test in overselectivity paradigm with the avatar