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Simplex didactics: promoting transversal learning through the training of perspective taking

Stefano Di Tore[a,1], Paola Aiello[a], Maurizio Sibilio[a], Alain Berthoz[b]

[a]*University of Salerno, Dept. of Education – Salerno (Italy)*

[b]*Collège de France, Lab. Physiology of perception – Paris (France)*

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Abstract

Several studies have focused on Visual Perspective Taking (from here on out "PT"). PT refer to the capacity to elaborate space from different perspectives. Research results led to the hypothesis that such an ability constitutes a milestone in the development of an individual's social skills, more specifically empathy, whose full development is at the basis of numerous school-related competencies. Even the national educational system seems to recognise the central role of the development of such skill in students' learning. To date, there is a lack of studies and teaching methods specifically designed to favour an adequate development of PT. The objective of this paper is to present the results of the validation of an edugame specifically designed to measure and promote the PT skill development.

KEYWORDS: Didactics, Edugame, Simplexity, Perspective Taking

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1. Introduction

In the late 1900s studies concentrated on better defining how the manipulation of space constitutes a prerequisite for the development of empathy in individuals. In particular, neuroscientific research identified the ability of spatial, (also referred to as visual and perceptual) PT a fundamental prerequisite for the development of empathy and agency (Underwood, 1982; Oswald, 1996; Ruby & Decety, 2001, 2003, 2004; David, 2006; Berthoz, 2006, 2011; Sibilio, 2017; Girelli, 2018). This ability has been considered a key milestone for the development of individual's social skills because "the capacity to know where another individual is directing attention in space and what he or she is seeing on the current visual scene, which we refer to as 'visual perspective taking', provides critical information for monitoring social interactions. It is likely a prerequisite to understand another's intentions, actions and emotional reactions, as well as to adapt one's own behaviour to the current situation" (Lambrey, 2008, p.523). Therefore, PT ability is at the basis of shared attention and constitutes one of the fundamental prerequisites for inter-individual differentiation. Psychological research has shown that these abilities depend on two cognitive systems to elaborate space (egocentric and allocentric) (Cornoldi, 2004; Surtees, 2012). Cornoldi links these two cognitive systems to the individual's motor skills and therefore to the individual's body in movement and describes them in the following manner: "As underlined above, the evolution of spatial competence has been linked to motor functions; thus the ability to move and find one's way in the environment clearly requires an understanding of the spatial properties of that environment. It is possible to encode spatial information in an egocentric or allocentric representation (Foreman & Gillet, 1997). An egocentric spatial representation refers to spatial encoding of information as a function of body position or a self-centred system of spatial coordinates. On the other hand, an allocentric spatial representation is based on the relationship between two or more objects in space.

[1] corresponding author

This relationship is defined not by means of the body's orientation or distance, but in terms of their spatial relations. It is clear that both egocentric and allocentric spatial representations are linked to motor functions, either in terms of grasping and reaching abilities (egocentric representations) or in terms of body movement and navigational ability (egocentric or allocentric representations)" (Cornoldi, 2004, p. 14). Berthoz locates these two mechanisms at the basis of four elaboration and recall strategies of space. These are:

1. *egocentric strategy* – this is used when we visit a city, on foot or by car. It consists in remembering our movements, the detours that we are made to take, and associate them to visual landmarks that we perceive or experiences we have lived. We have defined this as "topo-kinesthetic" memory. It doesn't limit itself to a simple association between movements and sensory data… It permits the perceiving subject, in other words us, to attribute a continuity, a structural organisation and a synthetic unity to the manifestation of instant sensorial fields. The surrounding world is hence constructed by the brain on successive views or sequentially-organised points of view: of encounters, events that happened while walking. This process is fundamentally egocentric. This means that the point of view through which the world is analysed is in the "first person".
2. *allocentric strategy* - This allows to recall a mental map of the environment on which we can follow an itinerary as if it were a real map. Imagine the neighbourhood in which you live and the way from your house to the bakery round the corner: you can recall the way – the first strategy – or the mental map of the neighbourhood, that is the second strategy, said to be allocentric because it does not envisage the body. In fact, the environmental elements are linked without making reference to the subject's body that examines the space.
3. *heterocentric strategy* – If somebody asked us "how do I get to the post office from the hotel?", and we have to describe the way from this person's perspective, we have to take this person as a point of reference. This decentralization also happens when during a row, we try to understand the litigants' point of view.
4. *3D model strategy* – This entails constructing a mental model of a tri-dimensional structure (Berthoz, 2015, p.87).

Regarding this issue, Berthoz writes: at this point I would like to insist on the use of space to simplify some processes which are highly cognitive. In fact, it seems to me that the neural basis of mental manipulation of spatial frame systems (egocentric, allocentric, geocentric, heterocentric, proximal and distal space) constitute one of the foundations of our rational thought and, in particular, of the human being's attitude towards geometry, reasoning, change in point of view and logic. It seems that these neural basis in cooperation with the social brain, make intersubjectivity and empathy possible (Berthoz, 2011, p.107). The ability to take somebody else's perspective would derive from a complex activity of manipulation of space. Understanding what another person is looking at, in fact, implies abandoning our spatial perspective (egocentric coding), being able to manipulate space independently from our position (allocentric coding) and, successively use the other person's perspective as the points of origin of the axis (heterocentric coding). Always in relation to PT, some studies have also demonstrated how this ability is significantly influenced in diverse sociopathies that affect the development of social interaction (autism, schizophrenia, paranoia) (Langdon, 2001, 2006; Reed, 1990; Dawson, 1987) thus supporting the hypothesis that this competence is of fundamental importance for the development of complex social competencies. More recent studies have focused on the identification of the active cerebral areas during PT tasks carried out by the individual or a third person (Ruby & Decety, 2001, 2003, 2004; Vogeley, 2001, 2004).

1.1 PT: Its development in childhood

Throughout the 20th Century, attempts were made to identify the way how PT ability develops during childhood and how this is manifested in adulthood. In Piaget's initial studies "children under approximately 7 years of age tended to choose their own view as also representing that of another observer (Piaget & Inhelder, 1956). These findings have been widely replicated (Fishbein, Lewis, & Keiffer, 1972; Flavell, Everett, Croft, & Flavell, 1981; Flavell, Flavell, Green, & Wilcox, 1981; Liben, 1978). Generally, it has been observed that correct performance on a perspective-taking task declines as the number of stimuli in the array increases (Fishbein et al., 1972; Liben, 1978). Poorer performance is also associated with an increase of interposition of the elements within the visual array and a decrease in the overall visibility of the stimulus set (Coie, Costanzo, & Farnill, 1973; Flavell, Omanson, & Latham, 1978; Liben, 1978). The angle of orientation also has an effect on performance. Broadside views of an arrray are mastered be- fore the comer or diagonal views (Schachter & Gollin, 1979; Walker & Gollin, 1977)" (Gzesh, 1985). However, a number of studies seem to suggest that even if three-year-olds perform poorly in visual perspective-taking tasks it is already possible to note a significant difference in terms of PT task performance in four-year-olds (age in which, according to Piaget, children are in high egocentric stage), who, on average, already seem to be able to carry our sophisticated manipulations of 3D space.

Flavell (1981) and Masangkay (1974) propose splitting PT ability in two levels: “Level 1 refers to the ability to distinguish between what people can and cannot see, e.g., that people who look at different sides of a piece of paper see different things: a picture of a cat on the one and a picture of a dog on the other side. Level 2 refers to the understanding that, when people look at the same drawing or scene from different angles, they arrive at different and contradictory descriptions” (Aichhorn, 2006, p. 1062) (Figures 1 and 2). Studies suggest that already when they are 4 years old, children are able to complete Level 1 PT tasks and therefore it can be acknowledged that “this knowledge undergoes considerable development during preschool period, with many 4.5-years-old seemingly possessing it in the form of a general rule”. Studies conducted by Flavell in the 60s and 70s also seem to suggest that children between 5 and 5.5 years seem to have already acquired excellent Level I and II PT abilities (Beilin, 2013). Hence, Flavell affirms that “there is widespread agreement today that young children are not as totally egocentric as Piaget believed them to be, but also that perspective-taking abilities and related psychological knowledge do show marked increases with age, much as he said they did” (Flavell, 2000, p.18). Nevertheless, the hypothesis that PT ability is “mastered in early adolescence (Chandler & Greenspan, 1972; Flavell, Botkin, & Fry, 1968; Laurendeau & Pinard, 1970; Piaget & Inhelder, 1956) has been challenged by several writers on methodological grounds. Borke (1975), Fishbein, Lewis, and Keiffer (1972), and Shantz and Watson (1971), for example, have argued that the late acquisition of coordinating perceptual perspectives is a function of the complexity of the stimulus array and response mode” (Kurdek, 1975, p.645). A study conducted by Kurdek in 1975 seems to suggest that PT ability starts to develop in pre-school years (at around 4 years of age) and proceeds until adolescence (around the age of 11). As a result, “the present finding of an increase in perceptual perspective taking in the fourth through sixth grades confirms Nigl and Fishbein's (1974) contention that the ability to coordinate perceptual perspectives undergoes marked performance changes between the ages of 9 and 11 years” (Kurdek, 1975. P. 647).

1.2 PT, mental rotation and gender differences

The study of the relationship between space elaboration and empathy reaches higher levels of complexity due to the coexistence of diverse systems and strategies to elaborate space. In fact, the existence of inter-individual differences and, more specifically, gender differences (Berthoz, 2011) add complexity to the studies on space elaboration and, more specifically on PT (Grön et al. 2000; Lambrey, 2007; Cahill 2006). For example, “it is well known that, in a given gender, some subjects are more dependent on visual inputs and information in their relation to space, whereas other subjects rely on proprioception. We also know that there are important gender differences: Women tend to adopt more egocentric strategies than men, whereas men adopt more allocentric strategies than women. It has been long known that women are more “field

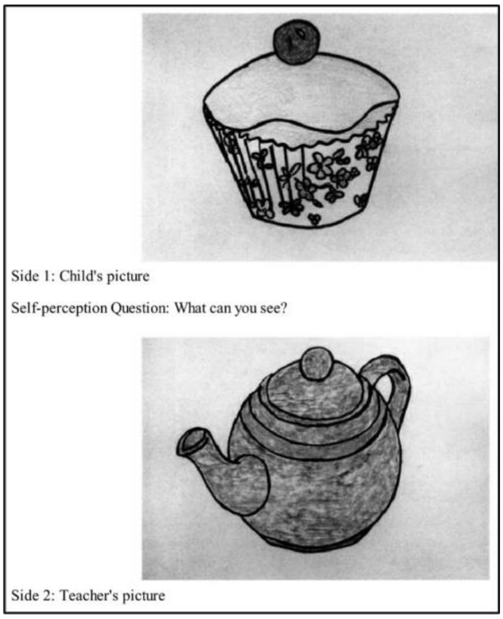

Figure 1 - Level I – PT Task.

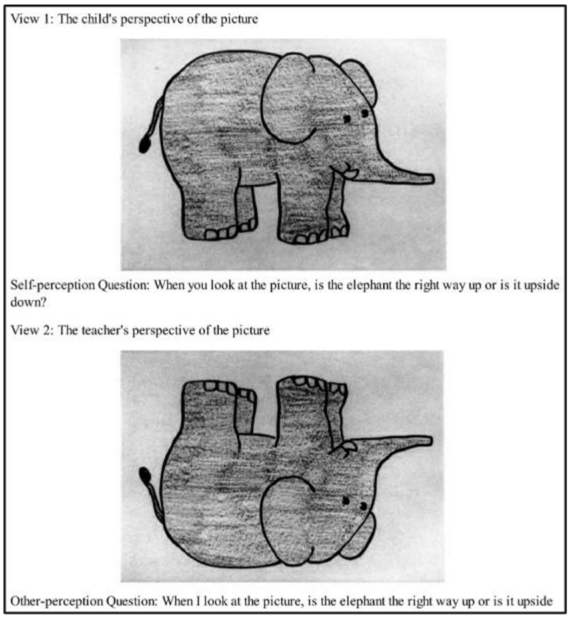

Figure 2 - Level II – PT Task.

dependent". This means that, for spatial orientation, women are more dependent upon visual references than men" (Berthoz, 2011). Moving beyond gender differences, literature seems to support the hypothesis that similar space elaboration tasks (such as imagining an object from different points of view and imagining that the object is rotating on its axis) require different cognitive abilities (PT in the first case, whereas Mental Rotation [MR] in the second case). The results conducted on this topic "suggest that the dissociation between tests of perspective taking and mental rotation reflects a distinction between ability to make egocentric spatial transformations (i.e., to imagine the results of changing one's egocentric frame of reference with respect to the environment) and ability to make object-based transformations (i.e., to imagine the results of changing the positions of objects in the environment, while maintaining one's current orientation in the environment)" (Hegarty, 2004, p 183).

Nevertheless, the distinction between MR and PT seems to be only partial. In fact, studies suggest that the MR and PT tasks shared a common skill (De Beni, 2006). Therefore, the two abilities not only seem to share some space elaboration skills but also the time when these skills develop. Indeed, various studies "showed that the elderly were less able than younger people in way-finding, route-learning and pointing tasks. Coyne and Herman (1980) found that the elderly was less accurate than younger people in a spatial perspective-taking test. Other studies (Lachman & Leff, 1989; Willis, 1991) support the adequacy of older participants in performing more everyday tasks. In Evans et al. (1984), ageing did not affect memory for salient landmarks or their position. Moreover, Kirasic (1989) found that the elderly was disadvantaged compared with younger people when having to solve spatial perspective-taking and mental rotation tasks operating on novel spatial configurations, but no differences between groups appeared when older people had to perform the tasks in a familiar environment. According to Kirasic (1985), elderly adults encountered problems only in learning new routes in unfamiliar areas. Overall, the pattern of results on spatial abilities in older people proved to be more disparate, indicating a dramatic drop in more abstract and laboratory tests but adequate performances in more everyday tasks" (De Beni, 2006, p. 815). In spite of the fact that the scientific debate seems to be heterogeneous, it is still possible to affirm that on the basis of what has been outlined in the section of PT development in childhood, PT ability matures in this developmental phase and presumably gradually deteriorates with time.

1.2 PT, Training Perspective Taking

A plethora of studies seem to demonstrate that the ability to elaborate space from an allocentric perspective could be trained through experience. Some studies have shown that the hippocampus of expert taxi drivers is bigger when compared to the average male drivers (Maguire, 1997, 2000, 2006). On the basis of the subjects studied, results have shown that these adaptations of the hippocampus is linked to a higher ability in tasks that require the allocentric elaboration of space. Therefore, the results correlate the spatial elaboration and navigation (derived from the taxi driver profession) to an increment in the ability of allocentric spatial elaboration. Therefore, an implicit result suggested by such studies is the ability to elaborate space allocentrically (and as a consequence PT ability) can be trained through specific tasks such as driving in big cities and changing the destination constantly (Chase, 1983; Maguire, 2000, 2003; Dünser, 2006). More specifically, studies have demonstrated the possibility to train PT by principally concentrating on subjects at a young age (Knoll, 2000; Rosen, 1974; Burns, 1979). In fact, Rosen (1974) reports a slight improvement in cognitive and perceptual perspective taking in kindergarten children who were given 40 hours of dramatic play training, while Cox (1978) reports significant improvements in PT ability in school-aged children, which he measured through the use of quasi-mountain problems prior to and after 20 hours of training.

2. Methods: Research Hypothesis

On the basis of what has been delineated in the introductory part of this paper, one can affirm that:

1. PT is a prerequisite for the development of social skills and the acquisition of literacy and numeracy skills (Trisciuzzi, 2014);
2. PT ability develops between the ages of 4 and 14 and gradually deteriorates over time after the ages 65-70 (De Beni, 2006);
3. The cerebral areas that are activated during PT and Mental Rotation tasks partially overlap and therefore they are only partially independent (Hegarty, 2004, p 183);
4. PT ability is affected by various sociopathies linked to deficits in social interaction (Kessler, 2012);
5. PT ability can be trained and improved (Chase, 1983).

The points listed above provide an explanation as to why this theme is undoubtedly of interest to the field of education. The objective of this study is related to the development of an edugame aimed to be used as a research tool to:

- measure the level of development of PT ability in children aged between 6 and 11 prior to and following a systematic didactic method planned to foster PT skill development;

- promote the development of PT ability in children aged between 6 and 11.

The design and development of the edugame responds to the need of having a reliable and objective tool apt to measure the levels of PT ability prior to, during and after the didactic interventions, fundamental requirement to guarantee an acceptable level of objectivity in the subsequent research phases.

In designing the testing phase of this edugame a number of difficulties were encountered. This was mainly due to the fact that the availability of validated standardised tests apt to measure PT ability are predominantly designed for adults. Those for school-aged children are not as accurate and reliable and are less feasible to use in school contexts than the edugame developed. Hence, the testing phase included two steps:

1. the edugame was tested with adults to explore the possible relation between the scores obtained in the edugame and those measured using the well-known and validated PTSOT test.
2. On acknowledging the fact that children are not 'little adults' (Remuzzi, 2015) and subject to the correlation emerging from the first step in the testing phase, a paper-and-pencil test was compiled. The items included in this test were extrapolated from other tests available in literature and those administered in national examinations by the Italian National Institute for the Evaluation of the Educational System. The aim was to demonstrate if and to what extent the edugame was able to measure the level of PT skill development among children – taking into consideration the differences between level I and II PT ability and the existence of other more complex components of PT ability.

2.1 Methodology

The *first* phase of the research consisted of three steps:

- literature review on PT;
- design of the Edugame - Schoolcam;
- creation of the Edugame - Schoolcam.

In the *second* phase the edugame was tested to evaluate whether and to what extent the tasks proposed in the edugame actually required PT ability. This was done by administering two validated tests, one measuring PT and one MR ability, and the edugame. The results obtained from the three tools were then compared. This phase, which was conducted with a sample of adult participants, included the following steps:

- standardized tests to measure PT and MR abilities were identified;
- the research sample was identified;
- the edugame and the two tests were administered;
- data was analysed.

The *third* phase is aimed at testing the tool on children to evaluate at what age, on average, children are able to carry out the proposed activities. Another objective of this research phase was to test whether the activities presented in the edugame were actually able to provide an adequate measurement of the level of PT ability in the targeted age group. To this aim, the paper-and-pencil test compiled, mentioned earlier and explained in detail later in this paper, was also administered when the edugame was tested.

2.2 The development of an edugame to promote the development of PT ability

The edugame created consists of three different tasks. The first two tasks measure the PT ability at two different difficulty levels. The third task measures Mental Rotation ability (understood as an ability which is partially independent from PT). The three tasks are described in further detail below:

TASK 1: In this activity the user is presented with a 3D classroom (Figure 3). The screen is divided into two frames. The frame above shows the 3D classroom through a semi-allocentric perspective (bird's eye view at an angle of 45°). The frame below shows the perspective of one of the students present in the frame above. The user is asked to identify to which student the view shown in the frame below belongs. Every time the user gives the correct answer, one point is awarded. No points are scored if the answer is wrong or no answer is submitted within 15 seconds.

TASK 2: In this activity a 3D classroom is presented (Figure 4). The screen is divided into two frames. The frame on the left shows the 3D classroom through an allocentric perspective (bird's eye view at a 90° angle). The frame on the right shows the point of view of the student presented in the frame on the left. The user is asked to identify to which student the view shown in the frame on the right belongs. Every time the user gives the correct answer, one point is awarded. No points are scored if the answer is wrong or no answer is submitted within 15 seconds.

TASK 3: In this activity a compex 3D object is shown (Figure 5). The screen is then divided into two frames. The frame above shows the 3D object from a specific perspective. Instead, in the frame below 4 objects are shown from different angles. Out of these 4, two show the same object shown in the frame above from a different perspective. The user must identify the two corresponding objects.

Furthermore, the edugame proposes two gameplay modes. One is aimed at measuring the user's ability, while the second mode is used for training purposes. In the first mode, the sequence of the questions and the respective spatial configurations are always the same

Figure 3 - Schoolca edugame screenshoot: Student perspective (first task).

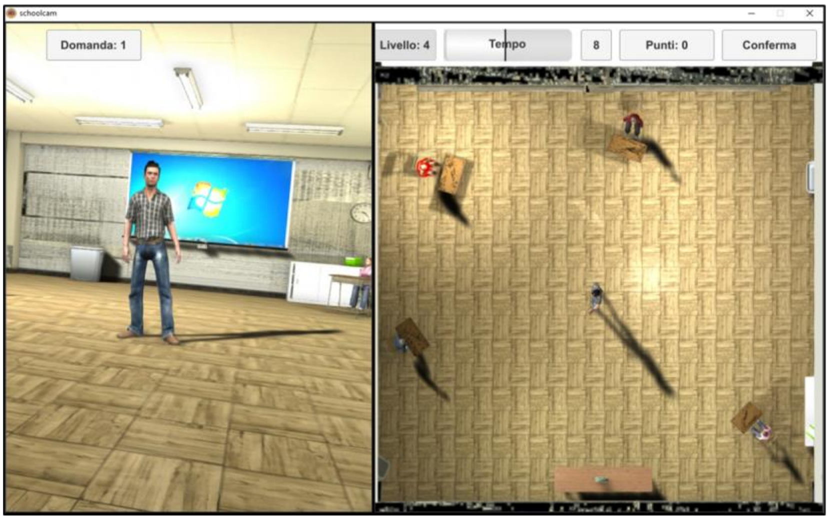

Figure 4 - Schoolca edugame screenshoot: Allocentric perspective (second task).

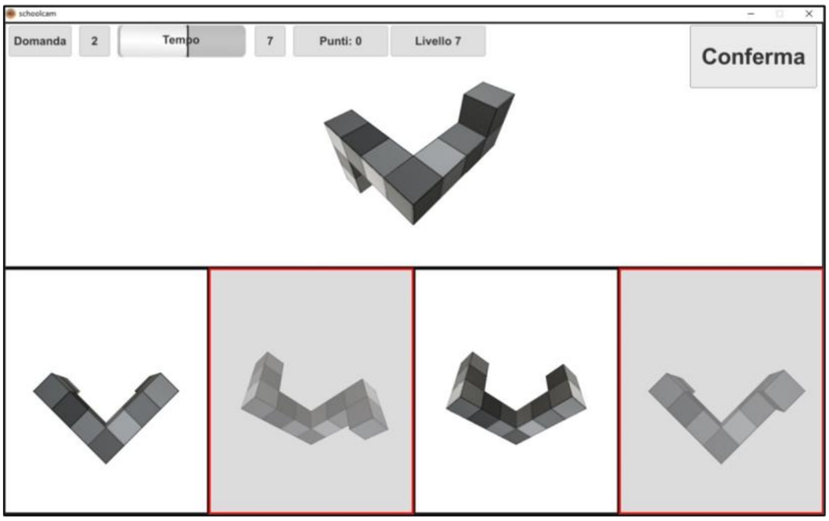

Figure 5 - Schoolca edugame screenshoot: Mental rotation task (third task).

and includes 15 questions, whereas the training mode the spatial configuration and the students and objects' positions are changed randomly. In both cases, the difficulty level gradually increases. The number of students increases with every 3 correct answers given, reaching a maximum of 15 students. The time available to answer each single question is 15 seconds. The edugame also has an automised system for data collection. The following data is recorded and exported in XLS and CSV formats:

- the time taken to give each single answer;
- the score for each question;
- the sequence of answers given for each task;
- the total score;
- the total duration to complete each level.

A demo video of the tasks and some experimental sessions can be viewed at: https://youtu.be/nkzjrVZKuek

2.3 Methodology – Phase II

The aim of the second research phase was that of validating the tool through the comparison of the scores obtained through the edugame and those obtained from the tests available in literature for the measurement of PT and MR competencies. The study involved a total of 122 subjects between the age of 30 and 63 (average age 48.6; SD 6.6). The methodology included the following steps:

- administration of the edugame;
- administration of the PTSOT and MRT-A tests (these will be described in the next section);
- data analysis.

2.4 Tests Used

As previously outlined, the first step in the testing phase consisted of administering two tests and the edugame. The first of these two tests is the PTSOT (Hegarty, 2004; Kozhevnikov, 2001) that measures perspective taking and spatial orientation abilities. Each of the pages includes:

- a group of objects
- a circle with an arrow
- a question related to the direction of objects from different perspectives (see Figure 6).

The instructions are the following:

"to answer each of the questions you should imagine that you are standing at one object in the array (which will be named in the centre of the circle) and facing another object, named at the top of the circle. Your task is to draw an arrow from the centre object showing the direction to a third object from this facing orientation" (Figure 6).

The score obtained in the test is simply calculated by measuring the angle discrepancy between that indicated by the respondent and the correct angle. Then, the average of the absolute values is calculated. Therefore, the test score is determined by the absolute average error, in terms of angles. Hence, the higher the score, the less the respondent's PT ability.

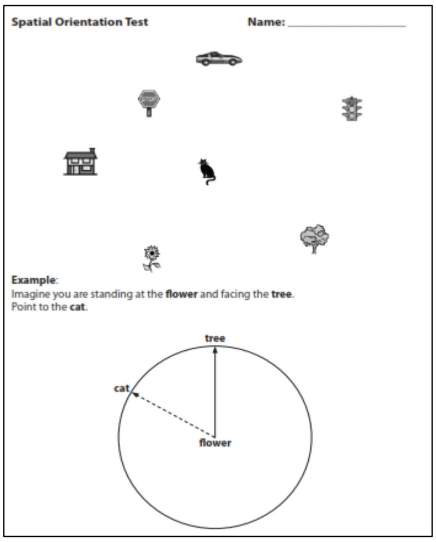

Figure 6 - PTSOT test.

The MRT-A (Peters, 1995) is a test which measures the mental rotation ability. Figure 7 shows the first page of the test with the instructions. Every time that the respondent chooses the two correct images that show the same image as the one on the left, a point is given. In this case, the higher the score, the higher is the respondent's mental rotation ability.

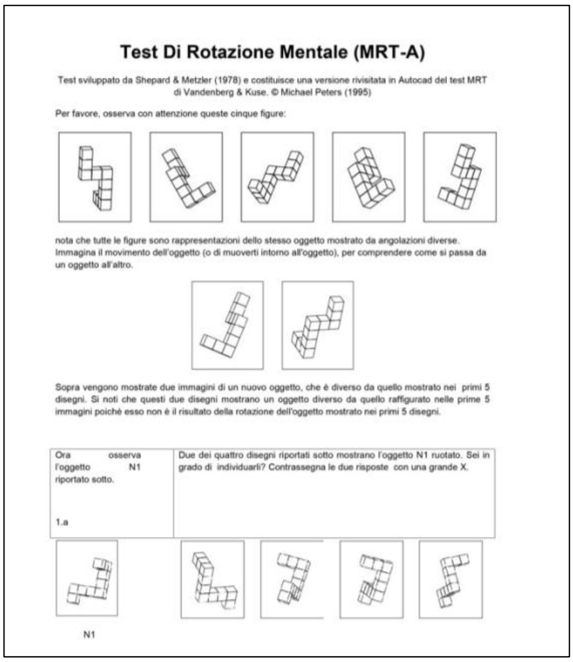

Figure 7 - Mrt-a TEST.

3. Results: Data analysis for phase 1

The PTSOT test, MRT-A test and the edugame developed were administered to 122 adults, aged between 30 and 63 (average age 48.6; SD 6.6). Table 1 presents the scores obtained, the time taken when playing the game (totals and subdivided per task) and the scores obtained in the PTSOT and MART-A tests. Table 1 presents the average scores obtained and the standard deviation values in the edugame by the 122 subjects.

Table 2 reports the standard scores available in literature and the average scores obtained in the PTSOT and MRT- A tests by the 122 participants.

As can be observed in Table 2, the scores obtained by the users in the MRT-A and PTSOT tests are below the standards reported in literature. Hence the Cronbach's alpha coefficient was calculated for the answers provided to measure the internal reliability of the test. The alpha coefficients are reported in Table 3.

The coefficients obtained are high enough to guarantee the internal reliability of the test. As a result, possible correlations between the scores obtained in the tests and those obtained in the edugame were calculated. Table 4 reports Pearson's R and R2.

In interpreting the data above, it is important to bear in mind that the PTSOT test measures the errors and so the higher the score the lower the PT ability, whereas the edugame scores measure the correct answers and so the higher the score the higher the PT ability. Therefore, as can be noted in Table 4, the obtained scores in the first task show a strong inverse correlation with the PTSOT test. Instead, the scores obtained in the second and the third task present a moderate correlation with the PTSOT scores. Even the total score shows a moderate correlation with the same PTSOT scores. There is a moderate inverse correlation between the scores obtained in the MRT-A test and the PTSOT test and a moderate direct correlation between the MRT-A test scores and the scores obtained in task 3 of the edugame, which was specifically designed to measure mental rotation ability.

A T-Test was carried out using the PTSOT and the MRT-A test scores. The T-test indicated a significant difference in terms of performance between the two tests ($p<0,0001$). The following graphs respectively show the correlation between the scores obtained in tasks 1 and 2 of the edugame and the PTSOT scores. On the basis of this data the percentiles were calculated. These are used as standard points for the edugame.

The data reported so far indicate the presence of a strong inverse correlation between the first task in the edugame and the results obtained by the participants in the PTSOT test. Hence, the first task of the edugame seems to partially measure the same abilities as those measured with the PTSOT test. The significant variation between the PT-SOT test and the MRT-A test confirm the difference between MR and PT, already stated in literature. Together with the intra-test reliability coefficients, these results support the hypothesis that the tests were correctly administered and that the participants completed the tests rigorously. The absence of correlation between the second and the third tasks in the edugame and PTSOT and MRT-A tests, leads to the conclusion that these two tasks do not measure the same abilities as the tests. Hence, they cannot be considered reliable to measure PT or MR. On the basis of these results, it was decided to go back to the design stage for the second and third tasks, whereas for the first task the results seem to be very encouraging. Therefore, the next testing phase concentrated solely on testing the first task among children.

3.2 Testing the first task of the edugame with children

The second step in testing the edugame aimed at exploring whether there were any correlations between the scores obtained in the edugame and the tests available in literature. Secondly, the testing also aimed at evaluating if the children would effectively be able to complete the task in the edugame and if the scoring obtained was suitable to provide a reliable measurement of the level of development of PT ability among children. The methodology adopted, therefore, was designed purposely to be able to establish a correlation between the results obtained in the edugame and the tests available for this age group. Taking into consideration the complexity related to the development of PT ability at this age (see paragraphs 3 and 4) and the scoring structure of the edugame, a paper-and-pencil test was compiled. Despite the fact that the tests used were extrapolated from tests available in literature and past national examinations, the use of these tests together has never been documented. The use of such tests addresses the need to verify if the first task of the edugame can actually measure the level of development of two different types of PT identified by Flavell and, eventually, also other more complex components that should be developed in this age range or beyond.

3.3 The paper-and-pencil test

The sequence of items used is composed of 8 tests, gradually increasing in difficulty. Figures 8 and 9 illustrate the first two test in this series that are the Three Mountains Test (Piaget, 1972) and a remodulation of it (Di Tore, 2014).

Figures 10 and 11 respectively report the third and fourth items in the test extrapolated from Flavell's Doll-Test.

Average PT Task 1	Average PT Task 2	Average PT Task 3	Average PT Tot
8.983606557	7.573770492	8.393442623	24.63114754
SD PT TASK 1	**SD PT TASK 2**	**SD PT TASK 3**	**SD PT Tot**
4.159989682	3.68135358	4.222249953	10.17467348

Table 1 - Edugame Scores.

Standard PTSOT	PTSOT SD	Standard MRT-A
24.53	14.9	11
Average score PTSOT	**PTSOT**	**Average score MRT-A**
79.34	44.83	6.33

Table 2 - PTSOT and MRT-A scores.

Cronbach's alpha PTSOT	**0.73884**
KR MRT-A	**0.67011**

Table 3 - MRT-A and PTSOT alpha coefficients.

Correlation	Edutask 1/PTSOT	Edutask 2/PTSOT	Edutask 3/PTSOT	Edutask Tot/PTSOT	MRT-A/PTSOT	Edutask3/MRT-A
R	-0.72	-0.42	-0.45	-0.61	-0.57	0.49
R^2	0.52	0.18	0.21	0.38	0.33	0.24

Table 4 – Correlations.

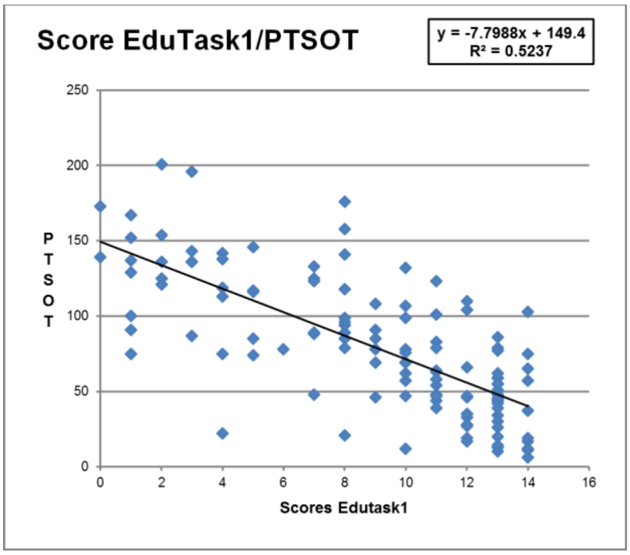

Figure 8 - Score EduTask1/PTSOT.

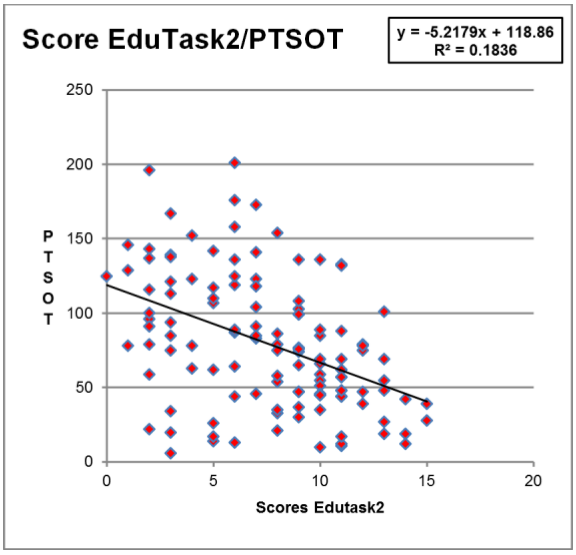

Figura 9 - Score EduTask2/PTSOT.

Figures 12 to 17 illustrate the tests extrapolated from national examinations (2012-2015) targeted for students aged between 7 and 13 years. The set of 8 tests was administered to the sample selected. The maximum number of correct responses was 9 since one test (Figure 14) included two questions. For every correct answer, one point was awarded. Wrong and unanswered responses weren't awarded any points.

The sample comprised 193 primary school pupils aged between 5 and 10 years. Both the edugame and the test were administered. The pupils were divided into three groups (5-6 years, 7-8 years, 9-10 years). The initial hypothesis was that the pupils:

- would have performed significantly differently both to the edugame and to the test on the basis of their age and gender;
- would have obtained correlated results both in the test and the edugame.

3.4 Data Analysis

Table 5 presents the descriptive statistics. The average scores and standard deviation are reported as a whole and per age group for both the paper-and-pencil test and Task 1 of the edugame.

Table 6 and Figures 18 and 19 present the disaggregated average scores based on gender and age.

The data illustrated seem to present different performances both in the test and task 1 of the edugame both in terms of gender and age. The only case where there is not an evident difference with regards to gender is the 9-10-year age group in the paper-and-pencil test. The internal coefficient of reliability of the scores obtained in the test (KR=0.74) ensures a satisfactory level of the internal coherence of the test. In order to normalize the data and identify an index able to comprehend not only the score but also the time taken to answer, the scores obtained in the test and the edugame were calculated using the following formula (Figure 20).

Where the:

- number of correct answers is given by the scores obtained;
- number of items is determined by the number of questions in the test (9 in the paper-and-pencil test, 15 in task 1 of the edugame).
- time available is the total time available to complete the test/task (1200 seconds for the paper-and-pencil test, 250 seconds in task 1 of the edugame)
- time taken is the time used by the child to answer each single item/question.

For example, considering a score of 4 points obtained in the Test Set with a total duration of 520 seconds, the normalised test score would be equal to:

$(4/9)*(1200-520)= 302.2$.

Similarly, considering a score of 6 points in the first task of the edugame, totalised in 164 seconds, the normalised score would be:

$(6/15)*(250-164)= 34.4$.

Successively, an ANOVA was conducted on the normalized scores, using age as a between factor. Both for the paper-and-pencil test and task 1 of the edugame, a statistically significant difference in performance in relation to age emerged ($p<0.001$). Tables 7 and 8 present the results for the paper-and-pencil test and task 1 of the edugame respectively.

A hypothesis test (T-test) was conducted to evalute the eventual presence of statistically significant differences in relation to the scores obtained by males and females in both the test and the task ($p= 0.0015$ and $p= 0.042$, respectively). In both cases statistically significant differences were present ($p<0.05$). The correlation index was calculated between the normalized points obtained in the test and the task ($R=0.62$) as illustrated in Table 9 and Figure 21.

4. Discussion

The correlation coefficient ($r=-0.72$) obtained from the scores attributed in the edugame and those obtained in the PTSOT test among adults appears to sustain the hypothesis that the edugame and the PTSOT partially measure the same cognitive ability (PT). Therefore, it seems plausible to sustain that the first task can be useful to assess the level of development of Pt ability in adults. As regards children aged between 5 and 10, the first task of the edugame also appears to be adequate to measure the development of PT ability both for level I and level II. In fact, on the basis of the data previously illustrated, the paper-and-pencil test used was in line with the initial hypotheses made. Indeed, the children participating in the study demonstrated different performances based on gender and age, as outlined in literature. It is also important to highlight that the activities related to level I PT ability were correctly answered by the vast majority of the children (87%), while the percentage of 5-year-olds that managed to answer correctly items testing level II PT ability was significantly lower (58%). These results are in line with the studies conducted by Flavell, conferring validity to the paper-and-pencil test used. The correlation coefficient obtained from the children's scores obtained in the paper-and-pencil test and in task 1 of the edugame ($r=0.6$) and the related tests carried out demonstrate the existence of a relation between the two tools used to measure the development of PT ability. The low R2 value may be interpreted as a non-linear correlation between the two series of data considered. Therefore, at this point, the linear model doesn't seem to be completely suitable to provide an explanation of

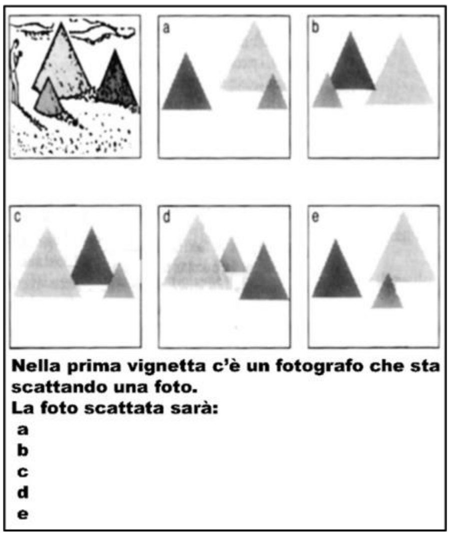

Figure 10 - Three Mountains Test.

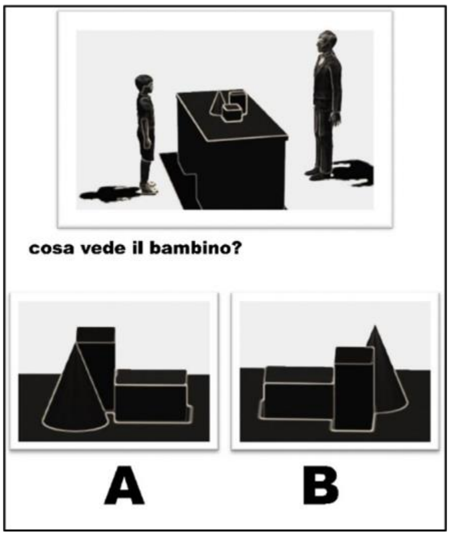

Figura 11 - Three Mountains Test revisited.

Figure 12 - Flavell's test revisited.

Figura 13 - Flavell's test revisited 2.

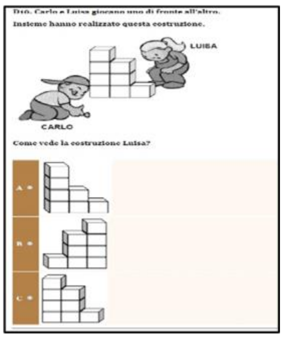

Figure 14 - Invalsi Test (primary School).

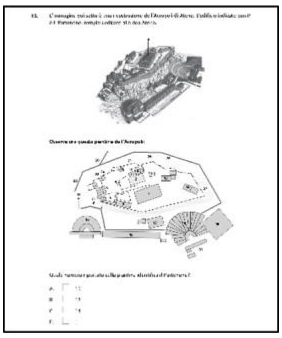

Figure 15 - Invalsi Test (first grade secondary school).

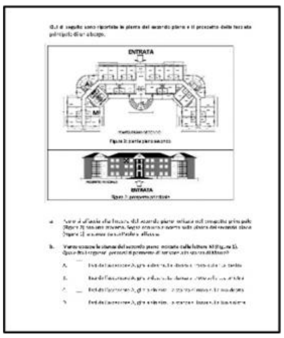

Figure 16 - Invalsi Test (high school).

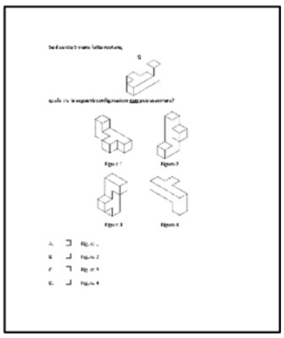

Figure 17 - Invalsi Test (high school).

	Average Score Test	Standard Deviation Test	Average Score EduTask1	Standard Deviation EduTask1
General	5.19	1.49	8.32	3.83
5\6 years	3.95	1.36	5.29	2.26
7\8 years	5.36	1.30	8.20	3.15
9\10 years	6.06	1.37	12.29	3.97

Table 5 - Descriptive Statistics.

		5\6 years		7\8 years		9\10 years		General	
		Test	Edutask1	Test	Edutask1	Test	Edutask1	Test	Edutask1
Female	**M**	3.70	4.61	4.95	7.27	6.07	11.71	4.80	7.28
	SD	1.40	2.04	1.28	3.06	1.44	4.07	1.52	3.71
Male	**M**	4.28	6.17	5.73	9.02	6.05	12.67	5.53	9.27
	SD	1.27	2.28	1.22	3.02	1.36	3.95	1.38	3.71

Table 6 - Disaggregated average scores based on gender and age.

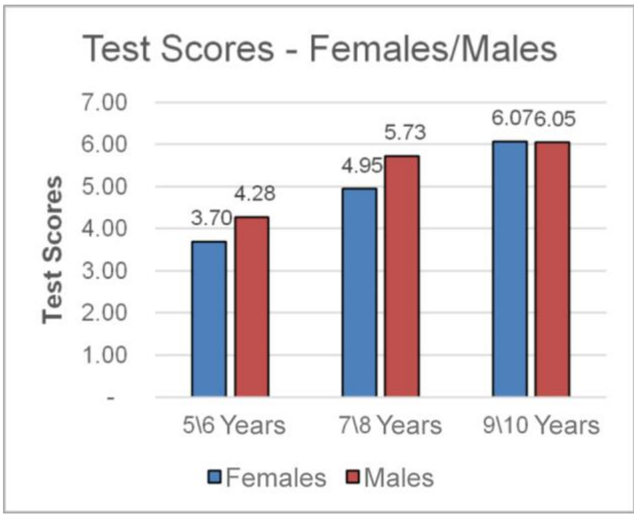

Figure 18 - Test Scores comparison - Females/Males.

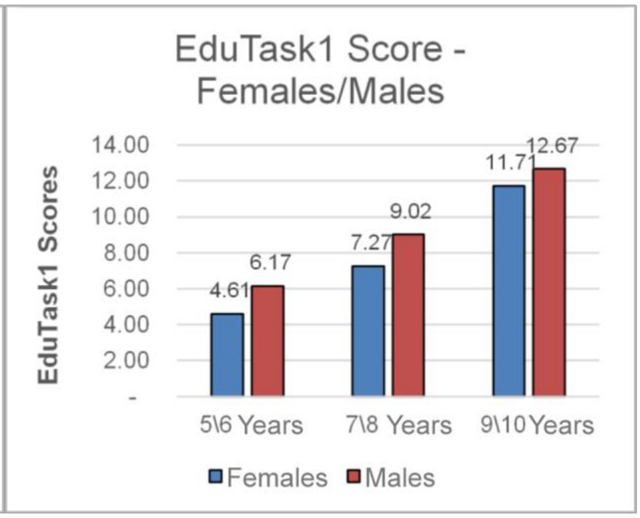

Figure 19 - Edugame first task score comparison (Male/Female).

$$\sum\left(\frac{\text{Correct answers}}{\text{Number of items}} * \frac{\text{Available time}}{\text{Used time}}\right)$$

Figure 20 - Formula used for calculating the score of the edugame.

Summary						
Group	*Count*	*Sum*	*Average*	*Variance*		
5\6 years	40	3,487.67	337.19	14,182.77		
7\8 years	116	2,129.00	449.39	11,998.55		
9\10 years	34	7,215.44	506.34	17,592.22		
Analysis of Variance (ANOVA)						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between groups	579520.67	2	289760.34	21.55762708	3.76092E-09	3.04
Within groups	2513504.05	187	13441.20			
Total	3093024.72	189				

Table 7 - Data output ANOVA – Test Scores.

Summary						
Groups	*Count*	*Sum*	*Average*	*Variance*		
5\6 years	41	1,138.80	27.78	520.86		
7\8 years	117	5,455.33	46.63	833.54		
9\10 years	35	3,154.07	90.12	1,793.54		
Analysis of Variance						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between groups	77858.00	2	38929.00	41.43576282	1.16295E-15	3.04
Within groups	178505.47	190	939.50			
Total	256363.47	192				

Table 8 - Data output ANOVA – EduTask1 Scores.

Regression Statistics		**ANOVA**					
R	0.62		*df*	*SS*	*MS*	*F*	*Significance F*
R squared	0.39	Regression	1	1228070.42	1228070.42	1.2E+02	5.0E-22
Adjusted R squared	0.38	Residual	191	1949675.04	10207.72		
Standard Error	101.03	Total	192	3177745.46			
Observations	193						

Table 9 - Analysis of Variance.

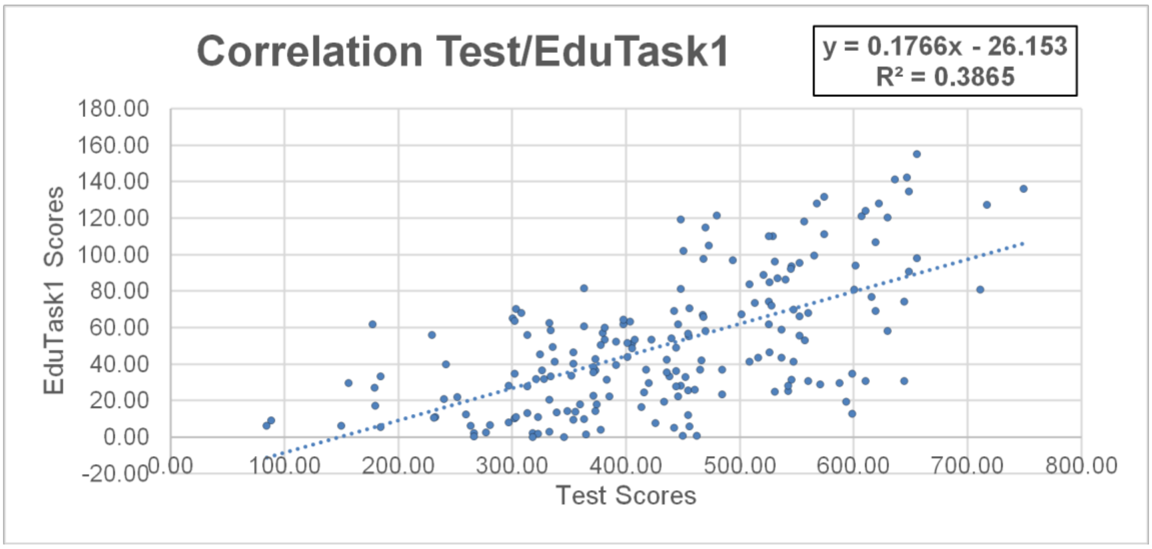

Figure 21 - Correlation Test/EduTask1.

the phenomenon being studied. Further studies will be conducted once the tests are administered to bigger samples of students in order to determine whether the inefficacy of this linear model is due to the inexistence of a non-linear correlation or because of the sample size. It is possible to sustain, however, that task 1 of the edugame is a reliable tool to measure level I and level II PT ability (as well as more complex components of PT) in childhood.

4.1 Conclusions and future perspectives

On the basis of the data collected, the first task of the edugame can be considered as a reliable tool for assessing the level of development of PT ability for children aged between 5 and 10 years. As regards the second and third tasks of the edugame, these are currently being redesigned. Successively, the same testing procedure will follow as for task 1. Future studies will examine the possibility of using task 1 of the edugame as a training tool to favour the development of PT for the age group considered. In relation to the design of a systematic teaching methods aimed at promoting the development of PT ability in primary school, one of the possible routes being explored is that of applying assessment protocols for the evaluation of PT that stem from studies conducted in the neuroscientific field.

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