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Children Perception of 3D Usual Shapes in Virtual Environments

Romain Beauset[1] & Dr. Prof. Natacha Durosin[1]

[1] Education and Learning Sciences Department, University of Mons, Mons, Belgium

Correspondence: Romain Beauset, Education and Learning Sciences Department, University of Mons, Mons, Belgium. E-mail: romain.beauset@umons.ac.be

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Abstract

Improving the understanding of the 3D perception spatial ability for children is an important issue for research in the areas of cognitive and developmental psychology, particularly in virtual environments where perceptive behaviors could differ from real environment. The aim of this research is to evaluate if children from 6 to 10 years old are able to perceive usual 3D shapes displayed in virtual environment like in 3D world.

In an experimentation, children (N =218) are split in groups faced with different modalities of representation of 3D shapes they are allowed to manipulate or only observe: virtual representations on touchpad or real representation with 3D models. They have to solve recognition task of usual 3D shapes (cube, cylinder, triangular prism, etc.). If results indicate that majority of children adequately perceived virtual usual 3D shapes, this ability is not acquired for everyone and is more problematic than perception of 3D models. Some shapes, like the triangular prism, were less adequately perceived. Results call for prudence regarding the use of virtual 3D shapes with children for example during 3D geometry learning.

Keywords: 3D perception, virtual environment, geometrical shapes, spatial cognition, developmental psychology, learning

1. Introduction

Children are more and more faced with representations that simulate 3D shapes in virtual environments. For example, during 3D geometry learning in primary school, some teachers use virtual representations of geometrical shapes displayed and manipulated on interactive whiteboard. These environments are also faced during leisure activities (videogames, etc.) and in adulthood in some professional sectors (architecture, engineering, medicine, etc.).

If several studies have investigated perception of 3D shapes with photos or with 2D representations (e.g. Brown, 1969; Bulthoff and Edelman, 1992; Frick and Newcombe, 2015), surprisingly any studies have investigated young children's perception of virtual representations of 3D shapes. Perhaps wrongly is this ability considered as a natural and unproblematic ability. By contrast with 3D perception ability, other spatial abilities, for example mental rotation or spatial orientation was investigated in virtual environments (e.g. Neubauer et al., 2010; Duroisin, 2015). However, 3D perception seems a prior ability in comparison with other 3D spatial abilities because deficit in perception process could impact other cognitive processes. Studying this ability is so a key issue to assure it is naturally acquired or to confirm children's potential difficulties in virtual environments.

Virtual representations of 3D shapes belong to a "2½D" world, between the physical world in three dimensions and the graphical world in two dimensions (Bertolo, 2014). In this world, shapes become dynamics and that conveys an impression of tridimensionality by giving cues about 3D information (Bakò, 2003). As such, perception of virtual representations requires mental reconstruction of the third dimension and could be problematic for children (Vivian et al., 2014). The perception of usual 3D shapes (cube, cone, etc.) displayed in a 2½D environment is investigated in this research in order to precisely study cognitive functioning of children in virtual environments.

2. Material Studied

By studying the way children reconstruct virtual 3D shapes in thought, the research focuses on the field of spatial cognition in a developmental perspective. This study attempts to address this principal question: Do children from 6 to 10 years old faced with geometrical 3D shapes displayed in virtual environment perceive these shapes accurately? Results of this study should help to confirm or infirm hypothesis of Rose and Foreman (1999) who declare that cognitive processing and perceptive behavior in virtual environment could differ from real environments. Specifically, different subquestions arise from the principal question: Do children perceive virtual 3D shape representations like they perceive 3D models of the same shapes? Do children better perceive virtual 3D shapes when they are allowed to manipulate it in comparison with observation of shapes? Does age of children impact ability of virtual 3D shapes perception? Does ability of virtual 3D shapes perception differ between shapes? Independent variables investigated are the type of 3D shapes representations children are faced with (virtual or real), actions allowed on these representations (manipulation or observation), age of children and shapes they must perceive (cube, sphere, etc.). Dependent variable is capacity to resolve exercise of 3D shapes perception.

3. Area Descriptions

Many cognitive processes, named spatial abilities, are involved in spatial cognition (Postma, 2017) and allow to reflect and reconstruct space in thought (Hart and Moore, 1973). The development of these abilities is fundamental for human life (Tzuriel and Egozi, 2010) because practically no tasks escape to spatiality. They impact achievement of daily tasks (Marchand, 2006; Rodán et al., 2019) and development of academic and professional skills (Mix et al., 2016; Verdine et al., 2017). Among those processes, Bishop (1983) identifies the Interpreting Figural Information (IFI) that are all processes that involve perception visual representations and that allow understanding and interpretation of information in those representations and recognition of shapes and objects (Barisnikov, 2009; Irani, 2011).

Acquisition of 3D shapes perception from 3D real world takes place as soon as child may move in space (Gordon and Yonas, 1976). Our visual system is able to reconstruct the third dimension with help of many visual cues even if visual images that arrive on the retina are two-dimensional (Bruce et al., 2003; Postma, 2017).

Very early in their child's life, children are faced with 2D representations of 3D objects (photos, realistic drawings, schematic diagrams). However, extracting spatial information from this type of representations can be difficult for children and perception of 3D shapes displayed with 2D representations is problematic for some children and teenagers (Beauset and Duroisin, 2022). Leighty et al. (2008) show that children gained reliable knowledge of object structure from 2D displays only from 4 years of age. Moreover, perception of schematic diagrams can be problematic for children and teenagers because this type of representation implies knowledge about convention that are required to avoid misinterpretations and ambiguity (Frick and Newcombe, 2015). This observation seems to be consistent with research in geometry didactic that highlights children difficulties about understanding plane representations of 3D geometrical objects (e.g. Pittalis and Christou, 2013; Kondo et al., 2014; Widder et al., 2019).

In addition to 2D representations, digital devices offer possibility to represent 3D objects: virtual representations in 2 ½ D environment. With these devices, frontiers between 3D objects and representations of these 3D objects are pushed (Lowrie, 2002). Several authors, for example Gutiérrez (1996) or Markopoulos et al. (2015), suggest that those types of representations could be pertinent for learning 3D geometry. A survey about teaching practice in France and French-speaking Belgium shows that this type of environments is not widely used even if some teachers used this materiel from the first years of school (Seha et al., 2023). According to Christou et al. (2006), using a virtual environment can enrich mental images of 3D shapes. Those representations are dynamics and simulate shapes in virtual environments. With their dynamic nature, virtual shapes can be rotated. Initial 2D representation evolves with a succession of plane information that offers hints about the third dimension that conveys an impression of tridimensionality (Bakò, 2003). Moreover, manipulation of virtual shapes is close to physical haptic object manipulation (Žilková and Partová, 2019) even if manipulation of 3D shapes in virtual environments can be not easy (Herndon et al., 1994; Bertolo, 2013).

In spite of the proximity between virtual representation and the real 3D world, the succession of plane information during movement of the virtual 3D shapes must be stocked in visual working memory and used to reconstruct the third dimension (Vivian et al., 2014). We must retain all information presented during the dynamic presentation of the object to construct a mental image of the shape that take into account retained information. The cognitive load generated with these types of representation can so be higher (Ayres and Paas, 2009; Höffler, 2010) and it is likely to impact 3D perception ability. Moreover, during rotation of shapes in virtual environments, children observe 3D shapes in “non-standard” positions and must imagine the shape during move when 2D elements (ex. side) shape changes. According to Larios (2003), with the phenomenon of “geometrical rigidity”, that can complicate the mental handle of shapes for certain children.

Currently, any studies have investigated the perception of 3D virtual shapes. In analogy with perception in 3D real space, this ability could be considered as unproblematic and natural for children. However, different above-mentioned arguments could be taken to suggest that difference exists between perception in real and virtual environment and so confirm hypothesis of Rose and Foreman (1999). These arguments invite to conduct investigations to identify if children are or not able to perceive 3D shapes displayed in virtual environment. This is a current issue because children are, in their daily life and sometimes in a school context, faced with virtual environments that simulate 3D space and 3D shapes. For example, during learning of 3D geometry, children must learn characteristics and properties of 3D shapes that can be displayed virtually. It seems logical to suggest that deficit of 3D shapes perception could impact understanding of geometrical properties and so create difficulties during learning. Beyond learning of 3D shapes, evaluating ability of perception in these environments is essential because this ability influences success in all tasks that implies them.

4. Method

4.1 Participants and Groups

The experimental sample is a convenience type of two hundred and eighteen (N=218) children between 6 and 10 years old. Informed consent was obtained from the parents.

Children of each age were randomly distributed into four groups (approximately 10 children per age) and each group was faced with a different presentation modality of 3D shapes. Size, average age and gender composition of groups are presented in Table 1. The average age of each group ranges from 8 years and 6 months to 8 years and 7 months. Man and woman breakdowns of the four groups are statistically equivalent (p-value of chi-square tests is 0.438).

Table 1. Sample (size, average age and gender breakdown)

	N	Average age	Gender breakdown (% of men)
G1: manipulation of 2½D	54	8 years and 6 months	55.5%
G2: observation of 2½D	54	8 years and 7 months	51.9%
G3: manipulation of 3D	56	8 years and 6 months	46.4%
G4: observation of 3D	54	8 years and 6 months	40.7%

Two variables are used to define the 3D shape presentation modality of each group: type of representation (virtual representations or 3D models) and action allowed on the representation (manipulation or observation). In the group 1 (N = 54), children are allowed to freely handle virtual colored 3D shapes displayed in linear perspective on a touchpad with tactile interface. Unity© software was used to design the virtual environment (Figure 1) created for the experimentation. The only one action permitted in the virtual environment is to rotate the virtual 3D shapes. Gestures made by the children caused so only rotation of the shape on the screen and not move or zoom the shape. The will was to use virtual environment as simple as possible to avoid a cognitive overload linked with use of technology (Bertolo, 2014).

When the child considers that he has sufficiently manipulated and observed the shape (any time limit is imposed with virtual 3D shape), he is requested to reset to its initial position with the green button. On average, time of manipulation per exercise is 15 seconds.

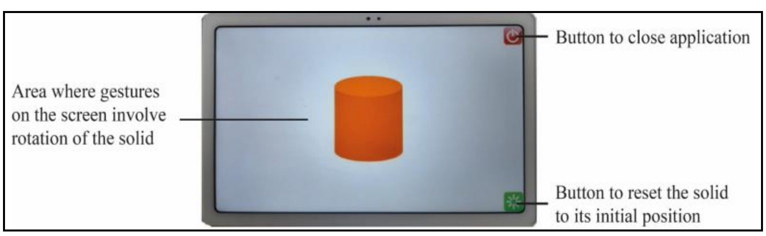

Figure 1. 2 ½ D virtual environment created (example of cylinder)

In the group 2 (N = 54), exactly the same virtual environment is used but children must only observe the virtual 3D shapes. Children from this group are so invited to observe videoclips of 3D shapes that rotate on the touchpad. For each 3D shape, video is approximately 35 seconds long. At the beginning of the video, the virtual 3D shape is presented in the position of the Group 1's shape before manipulation (see Figure 1 for the example of cylinder). The videoclip shows first a forward rotation to observe the top of the shape. After that, a backward rotation of the shape is carried out to show his front. Finally, the shape completely rotates to the left before returning to his initial position.

In the two last groups, children were given 3D models of shapes. Models are exactly the same (size, proportion and color) as 3D shapes displayed in virtual environment. Children from group 3 (N = 56) are allowed to freely manipulate (rotate) 3D models whereas children from the fourth group (N = 54) are only allowed to observe it.

4.2 Procedure

The experiment consists of an individual interview of approximately fifteen minutes conducted in scholar context. First, children are introduced to type of materials used in their group to familiarize with it, in particular to ensure the understanding of the virtual environment for group 1 and 2. During the familiarization time, an example of 3D and an example of 2D shapes are presented. Then, child have to solve seven recognition exercises of 3D shapes perception without training. In each exercise, one 3D shape is displayed in the modality of the group to which they belong. The order of exercises is the same for all children of the four groups: cylinder, cone, sphere, triangular prism, torus, cube, tube/hollow cylinder. Initial views of shapes are presented in Figure 2. Two parasite exercises are integrated during the experiment, the first between cylinder and cone exercise and the second between sphere and triangular prism exercise. These two exercises are similar recognition exercises but with 2D shapes and not 3D shapes. These exercises are not considered to evaluate 3D usual shapes perception.

Exercise 1	**Parasite exercise 1**	**Exercise 2**	**Exercise 3**	**Parasite exercise 2**	**Exercise 4**	**Exercise 5**	**Exercise 6**	**Exercise 7**
Cylinder 	Round 	Cone 	Sphere 	Square 	Triangular prism 	Torus 	Cube 	Tube/hollow cylinder 

Figure 2. Seven shapes investigated (initial position of shape in virtual environment) and parasite exercises

For each exercise, after the manipulation time (Group 1 and 3) or the video observation time (Group 2 and 4), 3D shapes are placed in initial position and different proposals of 2D (photos) and 3D objects (models) are presented (see example for the cylinder in Figure 3). Instruction is the same for participants of all groups: the child must choose proposal that is the element they have just seen by pointing it. He can choose one or zero proposal and must justify his choice orally.

Among the 3D proposals, there is the correct 3D shape and there are other incorrect close shapes. Like Frick and Newcombe (2015) who also investigate perception of 3D shapes, change about shape or proportion of the 3D shape are proposed. For example, extended shape, inclined shape, or deformed shape are presented. Among the 2D proposals, different views of the shape are presented (views of the shape in initial position or after rotation, views of the top or of the front of the shape). Figure 3 illustrates proposals for the first exercise by the way of example. For each exercise, the types of proposals are similar when it is possible.

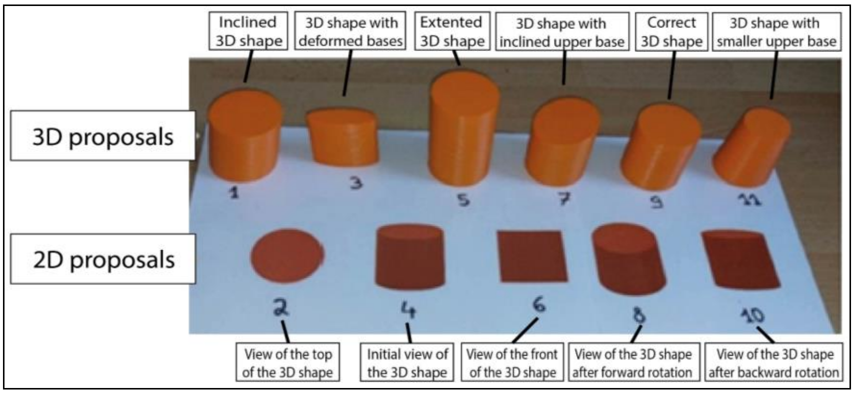

Figure 3. Proposals for «cylinder» exercise

4.3 Data Analysis

Responses of recognition task are used to understand how children perceive 3D. For all exercises, we will check if child selects the correct 3D shape. In this case, we consider that he adequately perceives 3D shape. A score out of 7 is calculated with the number of 3D shapes adequately perceived. For each group, we calculate the average number of shapes adequately perceived (score out of 7) and the percentage of children who adequately perceive 3D shape per exercise. Descriptive and inferential statistics of the above-mentioned score and percentages should allow us to identify if children faced with 2½D representations of 3D shapes perceived 3D shapes accurately or not in comparison with children faced with 3D models. Non-parametric inferential tests are applied because data of each group are not normally distributed (p-values of Shapiro-Wilk test: 0.000 for Group 1; 0.000 for Group 2; 0.001 for Group 3; 0.002 for Group 4).

5. Results

On average, children from 6 to 10 years old faced with virtual usual 3D shapes perceived adequately most of them: 5.09 out of 7 if they are allowed to manipulate virtual shapes (group 1) and 4.59 out of 7 if they only observe them (group 2). However, these scores are lower than scores of perception for children faced with 3D models (Table 2) that exceed 6 shapes out of 7. Observation of repartition of the number of adequately perceived 3D shapes shows that more than 50% of children perceived adequately all the shapes for group 3 and 4 (respectively 59.3% and 55.6%) while this rate is lower than 20% for group 1 and 2 (respectively 17.9% and 14.8%).

Mann–Whitney U tests confirm that virtual 3D shapes perception is significantly lower than 3D models perception: p-value of 0.000 (U = 846.0) is observed for comparison of manipulation groups (group 1 vs group 3) and also (U = 529.5) for comparison of observation groups (group 2 vs group 4).

Table 2. Number of shapes adequately perceived in each group (average and standard deviation)

	Average (out of 7)	S. D.
G1: manipulation of 2½D (N = 54)	5.09	1.443
G2: observation of 2½D (N = 54)	4.59	1.754
G3: manipulation of 3D (N = 56)	6.04	1.613
G4: observation of 3D (N = 54)	6.43	0.716

If majority of children adequately perceived the 3D shapes presented with 2½D representations, some of them also selected an incorrect 3D proposal. On average, children from group 1 choose a 3D incorrect proposal 1.13 out of 7 exercises and children from group 2 choose it 1.26 out of 7. In the two groups, the recuring 3D incorrect proposals is the extended 3D shape.

Out of 7 exercises, a 2D choice is selected on average 0.77 for children from group 1 and 1.11 for children from group 2. In group 1, the initial view of the 3D shape is the recuring 2D proposal chosen and it is the view after forward rotation in group 2. It is important to be cautious with interpretation of theses 2D choices because some children have chosen these proposals and argue that it was views of 3D objects they observed. Selecting 2D choice does not always mean that children are unconscious of 3D.

Mann–Whitney U tests are used to identify if manipulation impacts perception shapes of 3D shapes, by comparing manipulation and observation groups. Results indicate that manipulation does not impact virtual usual 3D shapes perception (U = 1280.5; p-value = 0.159) neither impact 3D models perception (U = 1499.0; p-value = 0.777).

To identify if virtual 3D shapes perception evolves with age, Spearman Correlation is calculated between number of 3D shapes adequately perceived and age. Table 3 presents results about these correlation rates for each group. Any correlation between 3D shape perception and age is significant. Kruskal-Wallis tests are applied in each group to identify if the number of 3D shapes adequately perceived are statistically equivalent in the fives age group. Results are unsignificant for all experimental groups (H of Kruskal-Wallis are respectively 2.236, 4336, 6.549 and 0.832; p-values associated are respectively 0.692, 0.362, 0.162, 0.934). It confirms that perception of 3D shapes displayed with virtual representation and 3D models seems not to fluctuate with age.

Table 3. Correlation between number of shapes adequately perceived and age (Spearman Rho)

	Correlation (Spearman Rho)	p-value
G1: manipulation of 2½D (N = 54)	0.230	0.088
G2: observation of 2½D (N = 54)	-0.093	0.505
G3: manipulation of 3D (N = 56)	-0.125	0.366
G4: observation of 3D (N = 54)	-0.130	0.349

Table 4 presents percentages of adequate perception for each shape and each group and shows that differences are observed between shapes. Results indicate that triangular prism is less adequately perceived than the other shapes by the children faced with virtual shapes. This shape is also one of the less perceived shapes in the group faced with 3D models. Cochran's Q tests are used to confirm that significant differences are observed between the seven shapes (Q for each group are respectively 23.389, 19.327, 21.409 and 29.233; p-values associated are respectively 0.001, 0.004, 0.002 and 0.000).

Table 4. Percentages of adequate perception per shape in each group

	Cylinder	*Cone*	*Sphere*	*Triangular prism*	*Torus*	*Cube*	*Tube*
G1: manipulation of 2½D (N = 54)	69.6%	71.4%	83.9%	50.0%	82.1%	76.8%	75.0%
G2: observation of 2½D (N = 54)	70.4%	64.8%	70.4%	44.4%	61.1%	77.8%	70.4%
G3: manipulation of 3D (N = 56)	87.0%	81.5%	92.6%	72.2%	88.9%	90.7%	90.0%
G4: observation of 3D (N = 54)	92.6%	96.3%	100.0%	81.5%	92.6%	100.0%	79.6%

McNemar tests are used to compare pairs of shapes in each group. The results show that, in Group 1, there is only a significant difference between triangular prism and cone (p-value = 0.038), sphere (p-value = 0.001), torus (p-value = 0.002), cube (p-value = 0.004) and tube (p-value = 0.007), always in disfavor of the triangular prism. This shape is so significantly different from almost all the others 3D shapes evaluated.

In group 2, triangular prism significantly lower than all 3D shapes evaluated except torus. P-value are 0.014 for the cylinder, 0.035 for the cone, 0.003 for the sphere, 0.000 for the cube and 0,003 for the tube. Any else pair of 3D shapes is significantly different.

In group 3, only differences between triangular prism and sphere (p-value = 0.001), torus (p-value = 0.012), cube (p-value = 0.006) and tube (p-value = 0.013) are significant, always in disfavor of triangular prism.

Finally, in group 4, two shapes are less adequately perceived: tube and triangular prism. Significant difference between these two forms and cone (p-values are respectively 0.022 and 0.008), sphere (p-values are respectively

0.001 and 0.002) and cube (p-values are respectively 0.001 and 0.002) are observed.

6. Discussion

Considering, on the one hand, the impact of spatial abilities for achievement of academic, professional and daily tasks (Wright et al., 2008; Mix et al., 2016; Verdine et al., 2017; Rodán et al, 2019) and, on the other hand, the emphasis of virtual 3D environments (for example in certain professional sectors like architecture and engineering), investigation of spatial cognition within virtual environments is a current issue. This experiment investigates the acquisition of the 3D shape perception spatial ability in virtual environment. Particularly, this ability is studied for children from 6 to 10 years old presented with virtual usual geometrical 3D shapes in comparison of 3D real models. The results of the study complete achievements of prior research about cognitive functioning of other spatial abilities in virtual environment (e.g. Parsons et al., 2004; Neubauer et al.,2010; Beauset and Duroisin, 2023) and contribute in understanding of these research' results because deficit of 3D perception could explain deficit in other spatial abilities.

Results confirm hypothesis of Rose and Foreman (1999) about perceptive behaviors potentials differences between real and virtual environment because children faced with 3D models better perceived 3D shapes than children faced with virtual representations. This leads us to believe that seeing in a virtual space is not exactly the same than seeing in the real world.

Despite the difference between virtual and real shapes perceptions, results indicate that majority of children correctly perceived virtual usual 3D shapes on the touchpad. The impression of tridimensionality conveys in virtual environment (Bakó, 2003) seem to be sufficient for most of them. However, the perception of shapes in a virtual environment is not systematic also for 10-year-olds. Results so confirm that it can be problematic to visualize an object in space (e.g., Mithalal, 2014), even in virtual environment (Beauset and Duroisin, 2024). Some children selected incorrect 3D proposals and so perceived the third dimension, but inadequately. They choose in most cases proposal that do not respect proportions of the 3D shapes. That can be explained with a misunderstanding of the virtual environment. Indeed, to justify their choice, several children explained that it is not possible to know the size of the shape in virtual environment. They so confuse size and proportion of shapes. If we cannot know the exact size of a shape presented in virtual environment, proportions are conserved in this type of space. Another explanation about error of perception can be linked with the cognitive load generated with this type of environment (Ayres and Paas, 2009; Höffler, 2010). Indeed, with virtual representations of 3D shapes, children must retain different information presented during shapes move. Children who have not adequately perceived 3D shape have maybe not retained some essential spatial information about the shape. For example, as 3D proposal "extended shape" is a recurrent error, children maybe do not retain information about front view of shapes. Moreover, difficulties can also be explained by geometrical rigidity phenomenon. They must observe moving shapes and are faced with non-standard positions of shapes which can be problematic (Larios, 2003). For example, they must understand that view of a side of the cube in virtual environment evolve with movement of the 3D shape. The side is represented with a square when they observe the front of the cube but becomes a rectangle, a rhombus or a parallelogram or even becomes invisible when the cube rotates.

If some children selected 3D incorrect proposals, some other children select 2D proposals. That may signify that they do not grasp 3D in virtual space and they were not able to reconstruct mentally the third dimension. This result seems to be consistent with Vivian et al. (2014) who consider that the ability of third-dimension mental reconstruction from dynamic information can be problematic for some learners. However, verbatims of children during experiment invite to stay cautious with this interpretation of this type of choice. Some children explained that they had chosen a 2D proposals but were aware that her choice was a view or representation of the 3D shape they had seen. This reflects a misunderstanding of instruction because we wanted that children chose the exact element and not a representation of this element.

Age of children between 6 to 10 years old seems to have any impact on 3D simple virtual shapes perception. This result is inconsistent with the fact that spatial ability evolves with age (Uttal et al., 2013). However, this experiment must be replicated with younger children to identify if they also performed like 6 to 10 years old children, and with children over the age of 10 to identify if the score obtained can still evolve or if the score is also stabilized around a maximum score (ceiling effect).

Results show some 3D shapes, like triangular prism, seems to be less adequately perceived than other shapes. We can so consider that ability of virtual shapes perception is not a general process, but it is dependent from the shapes children are faced. This result is consistent with anterior research that show the same observation for other spatial abilities, for example spatial visualization (Duroisin and Demeuse, 2016). These results in disfavor of triangular prism can be explained by the fact that learners are less frequently faced with this 3D object than with the other in school or everyday life context. If this experiment focuses only on 3D usual shapes, it could be interesting to replicate this experiment with more complex stimuli, for example combinated objects like Meijer and van den Broek (2010) or Frick and Newcombe (2015). This type of stimuli could be more discriminant.

Impact of manipulation is investigated in virtual space by comparing results from group 1 and 2. Results indicate that there is no impact of manipulation on ability of simple virtual 3D shapes perception. However, according to James et al. (2002), manual interactions can foster the development of integrated concrete knowledge and impact construction of mental representations of shapes The results can highlight the fact that, for children, manipulation of shapes does not offer because integrated concrete knowledge has already been developed for most learners. Moreover, lack of impact of manipulation in the experimentation could be explained by the complexity of interaction with a simulation of a 3D space via a 2D interaction modality (Cohé, 2012). If virtual representations of 3D shape could be offered on tablet with a tactile interface to manipulate virtual objects, some modern alternatives integrate augmented reality devices (Kaur et al., 2018). This new technology increases the degrees of freedom for input and provides well-suited and more natural 3D interactions (Kratz et al., 2012; Kaur et al., 2018). It could be interesting to evaluate 3D perception in virtual environment with this type of device in comparison with touchpad device to identify if in this context, manipulation impacts performances.

7. Conclusion

In this experiment, we evaluate if children from 6 to 10 years old are able to perceive adequately 3D usual shapes (cube, cylinder, etc.) when they are displayed in virtual environment on touchpad, in comparison with shapes presented in the real environment with models. Principal results show that 3D perception ability differs from real to virtual space. If children from 6 to 10 seem to easily perceive 3D models, perception of the same shapes displayed in a virtual environment is more problematic. Perception of usual virtual 3D shapes is not systematic also for 10-year-old children even if majority of children adequately perceived simple virtual shapes.

In addition to enriching knowledge about spatial functioning of children in virtual environment, results can also engage reflection about utilization of this type of environment with children. Indeed, the 3D perception ability, studied in this research, is used by children as they are faced with this type of environment, for example, in some psychometric test. We must stay cautious with these tests because deficit of performance could so be caused by their perception ability and not by difficulties with ability evaluated. Similar limits area associated with paper and pencil test that use plane representations of 3D shapes (Rahe and Quaiser-Pohl, 2022).

The practical implications of this experiment surpass the fields of cognitive and developmental psychology because this type of environment is sometimes used in 3D geometry learning and in other school subjects (for example in sciences to represent molecules or body part). Teachers must be aware that children do not always correctly perceive virtual 3D shapes. If this learning material is used, teachers must support learners with deficit of perception to avoid that these difficulties negatively impact learnings. This support could be possible by considering that, for these learners, virtual shapes are not learning device that can replace models but that is used initially as a complement to help with transition between 3D and 2 ½ D spaces.

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References

Ayres, P., & Paas, F. (2009). Interdisciplinary perspectives inspiring a new generation of cognitive load research. *Educational Psychology Research, 21*, 1-9. https://doi.org/10.1007/s10648-008-9090-7

Bakó, M. (2003). Different projecting methods in teaching spatial geometry. *Proceedings of the Third Conference of the European society for Research in Mathematics Education.*

Barisnikov, K. (2009). Les troubles des fonctions visuo-spatiales. In M. Poncelet, S. Majerus, & M. Van der Linden (Eds.), *Traité de neuropsychologie de l'enfant*. Marseille, France: Solal.

Beauset, R., & Duroisin, N. (2022). Etude expérimentale de l'habileté visuo-spatiale relative à la perception de la 3D en environnements virtuels auprès des enfants de 6 à 12 ans. *Paper presented at the 14th international forum of RIPSYDEVE, Montpellier.*

Beauset, R., & Duroisin, N. (2023). Evaluer l'habileté de visualisation spatiale chez les élèves âgés de 12 à 15 ans: des résultats différents selon le matériel utilisé? *Paper presented at the annual forum of ADMEE-Europe*, Mons.

Beauset, R., & Duroisin, N. (2024). L'évaluation des habiletés spatiales au service de l'enseignement-apprentissage de la géométrie tridimensionnelle : qu'en est-il des environnements virtuels 2 ½ D? In N. Loye, & N. Duroisin (Eds.), *Évaluation des apprentissages et technologies numériques: évolution, nouveautés et défis actuels*. Peter Lang.

Bertolo, D. (2013). Les Interactions sur Tablettes Multi-touch améliorent-elles l'Apprentissage de la Géométrie dans l'Espace?. *Paper presented at the 25th French-speaking conference on Human-Computer Interaction,* IHM'13, Bordeaux, Belgique.

Bertolo, D. (2014). Apports et évaluations des interactions sur tablettes numériques dans le cadre de l'apprentissage de la géométrie dans l'espace (*Doctoral thesis*). Université de Lorraine, France.

Bishop, A. J. (1983). Spatial abilities and mathematical thinking. In M. Zweng, *et al.* (Eds.), *Proceedings of the IV I.C.M.E.* (pp. 176-178). Birkhäuser : Boston, USA.

Brown, L. B. (1969). The 3D reconstruction of a 2D visual display. *The Journal of Genetic Psychology, 115*, 257-262. https://doi.org/10.1080/00221325.1969.10533893

Bruce, V., Green, P. R., & Georgeson, M. A. (2003). *Visual perception: Physiology, psychology, and ecology* (4th ed.). Psychology Press.

Bulthoff, H., & Edelman, S. (1992). Psychophysical support for a two-dimensional view interpolation theory of object recognition. *Proceedings of the National Academy of Sciences, 89*, 60-64. https://doi.org/10.1073/pnas.89.1.60

Chikha, A. B., Khacharem, A., Trabelsi, K., & Bragazzi, N. L. (2021). The Effect of Spatial Ability in Learning From Static and Dynamic Visualizations: A Moderation Analysis in 6-Year-Old Children. *Frontiers in Psychology, 12*. https://doi.org/10.3389/fpsyg.2021.583968

Christou, C., Jones, K., Mousoulides, N., & Pittalis, M. (2006). Developing the 3dmath dynamic geometry software: theoretical perspectives on design. *International Journal for Technology in Mathematics Education, 13*(4), 168-174.

Cohé, A. (2012). Manipulation de contenu 3D sur des surfaces tactiles. Interface homme-machine (*Doctoral thesis*). Université Sciences et Technologies - Bordeaux I, France.

Duroisin, N. (2015). Quelle place pour les apprentissages spatiaux à l'école ? Etude expérimentale du développement des compétences spatiales des élèves âgés de 6 à 15 ans (*Doctoral thesis*). Université de Mons, Belgique.

Duroisin, N., & Demeuse, M. (2016). Le développement de l'habileté de visualisation spatiale en mathématiques chez les élèves âgés de 8 à 14 ans. *Petit X, 102*, 5-25.

Frick, A., & Newcombe, N. (2015). Young Children's Perception of Diagrammatic Representations. *Spatial Cognition & Computation, 15*(4), 227-245. https://doi.org/10.1080/13875868.2015.1046988

Gordon, F. R., & Yonas, A. (1976). Sensitivity to binocular depth information in infants. *Journal of Experimental Child Psychology, 22*, 413-422. https://doi.org/10.1016/0022-0965(76)90105-3

Gutiérrez, A. (1996). Visualization in 3-dimensional geometry: In search of a framework. In L. Puig, & A. Gutiérrez (Eds.), *Proceedings of the 20th conference of the International Group for the Psychology of Mathematics Education* (vol. 1, pp. 3-19). Valencia: Universidad de Valencia.

Hart, R. A., & Moore, G. T. (1973). *The development of spatial cognition: a review, in Image and Environment: Cognitive Mapping and Spatial Behavior.* Chicago, USA: Aldine Publishing Company.

Herndon, K., van Dam, A., & Gleicher, M. (1994). The challenges of 3D interaction. *SIGCHI Bulletin, 26*(4), 36-43. https://doi.org/10.1145/191642.191652

Höffler, T. N. (2010). Spatial ability: its influence on learning with visualizations—a metaanalytic review. *Educational Psychology Review, 22*, 245-269. https://doi.org/10.1007/s10648-010-9126-7

Irani, F. (2011). Visuospatial ability. In J. S. Kreutzer, J. DeLuca, & B. Caplan (Eds.), *Encyclopedia of Clinical Neuropsychology* (pp. 2656-2656). Springer: New York.

James, K. H., Humphrey, G. K., Vilis, T., Corrie, B., Baddour, B., & Goodale, M. A. (2002). "Active" and "passive" learning of three-dimensional object structure within an immersive virtual reality environment. *Behavior Research Methods, Instruments, & Computers, 34*, 383-390.

Kaur, N., Pathan, R., Khwaja, U., & Murthy, S. (2018). GeoSolvAR: Augmented Reality Based Solution for Visualizing 3D Solids. 2018 IEEE 18th International Conference on Advanced Learning Technologies

(ICALT). https://doi.org/10.1109/icalt.2018.00093

Kondo, Y., Fujita, T., Kunimune, S., Jones, K., & Kumakura, H. (2014). The influence of 3D representations on students' level of 3D geometrical thinking. In *Proceedings of PME 38 and PME-NA 36* (Vol. 4, pp. 25-32).

Kratz, S., Rohs, M., Guse, D., Müller, J., Bailly, G., & Nischt, M. (2012). PalmSpace. *Proceedings of the International Working Conference on Advanced Visual Interfaces,* 181-188. https://doi.org/10.1145/2254556.2254590

Landy, M. S., Maloney, L. T., Johnston, E. B., & Young, M. (1995). Measurement and modeling of depth cue combination: In defense of weak fusion. *Vision Research, 35*(3), 389-412. https://doi.org/10.1016/0042-6989(94)00176-M

Larios, O. V. (2003). Geometrical rigidity: An obstacle in using dynamic geometry software in a geometry course. *Paper presented at the 3rd Conference of the European Society for Research in Mathematics Education,* Bellaria, Italy.

Leighty, K. A., Menzel, C. R., & Fragaszy, D. M. (2008). How young children and chimpanzees (Pan troglodytes) perceive objects in a 2D display: Putting an assumption to the test. *Developmental Science, 11*, 778-792. https://doi.org/10.1111/j.1467-7687.2008.00729.x

Lowrie, T. (2002). The influence of visual and spatial reasoning in interpreting simulated 3D worlds. International *Journal of Computers in Mathematical Learning, 7*(3), 301-318. https://doi.org/10.1023/A:1022116221735

Marchand, P. (2006). Comment développer des images mentales liées à l'apprentissage de l'espace en trois dimensions?. *Annales de didactique des mathématiques et des sciences cognitives*, *11*, 103-121.

Markopoulos, C., Potari, D., Boyd, W., Petta, K., & Chaseling, M. (2015). The Development of Primary School Students' 3D Geometrical Thinking within a Dynamic Transformation Context. *Creative Education, 6,* 1508-1522. https://doi.org/10.4236/ce.2015.614151

Meijer, F., & van den Broek, E. (2010). Representing 3D virtual objects: Interaction between visuo–spatial ability and type of exploration. *Vision Research*, *50*, 630-635. https://doi.org/10.1016/j.visres.2010.01.016

Mithalal, J. (2014). Voir dans l'espace: est-ce si simple?. *Petit x, 96*, 51-73.

Mix, K. S., Levine, S. C., Cheng, Y. L., Young, C., & Hambrick, D. Z. (2016). Separate but correlated: The latent structure of space and mathematics across development. *Journal of Experimental Psychology: General, 145*(9), 1206-1227. https://doi.org/10.1037/xge0000182

Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, M. (2001). How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. *Journal of Experimental Psychology: General, 130*(4), 621-640. https://doi.org/10.1037//0096-3445.130.4.621

Neubauer, A. C., Bergner, S., & Schatz, M. (2010). Two-vs. three-dimensional presentation of mental rotation tasks: sex differences and effects of training on performance and brain activation. *Intelligence*, *38*, 529-539. https://doi.org/10.1016/j.intell.2010.06.001

Parsons, T. D., Larson, P., Kratz, K., Thiebaux, M., Bluestein, B., Buckwalter, J. G., & Rizzo, A. (2004). Sex differences in mental rotation and spatial rotation in a virtual environment. *Neuropsychologia, 42*(4), 555-562. https://doi.org/10.1016/j.neuropsychologia.2003.08.014

Piaget, J., & Inhelder, B. (1948). *The Child's Conception of Space*. New York: W. W. Norton.

Pittalis, M., & Christou, C. (2010). Types of reasoning in 3D geometry thinking and their relation with spatial ability. *Educational Studies in Mathematics, 75*(2), 191-212. https://doi.org/10.1007/s10649-010-9251-8

Postma, A. (2017). A Sense of Space. In A., Postma & I., van der Ham (Eds.), *Neuropsychology of Space: Spatial functions of the human brain* (pp. 1-34). Elsevier Academic Press. https://doi.org/10.1016/B978-0-12-801638-1.00001-X

Rahe, M., & Quaiser-Pohl, C. (2023). Protective effects of education on the cognitive decline in a mental rotation task using real models: a pilot study with middle and older aged adults. *Psychological Research, 87,* 1284-1292. https://doi.org/10.1007/s00426-022-01719-2

Rodán, A., Gimeno, P., Elosúa, R., Montoro, P., & Contreras, M. J. (2019). Boys and girls gain in spatial, but not in mathematical ability after mental rotation training in primary education. *Learning and Individual Differences*, 70, 1-11. https://doi.org/10.1016/j.lindif.2019.01.001

Rose, D., & Foreman, N. (1999). Virtual reality. *Psychologist, 12*(11), 550-554.

Seha, M., Beauset, R., & Duroisin, N. (2023). Une géométrie qui fait sens. *Cahiers Pédagogiques, 586,* 31-32.

Tzuriel, D., & Egozi, G. (2010). Gender Differences in Spatial Ability of Young Children: The Effects of Training and Processing Strategies. *Child Development, 81*(5), 1417-1430. https://doi.org/10.1111/j.1467-8624.2010.01482.x.

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills : A meta-analysis of training studies. *Psychological Bulletin, 139*(2), 352-402. https://doi.org/10.1037/a0028446

Verdine, B. N., Golinkoff, R. M., Hirsh-Pasek, K., & Newcombe, N. S. (2017). Links between spatial and mathematical skills across the preschool years. *Monographs of the Society for Research in Child Development, 82*(1), 7-30. https://doi.org/10.1111/mono.12280

Vivian, R., Bertolo, D., & Dinet, J. (2014). Interactions tactiles sur tablettes pour l'apprentissage de la géométrie dans l'espace : présentation et premières évaluations. *Revue des Interactions Humaines Médiatisées, 15*(1), 51-90.

Widder, M., Berman, A., & Koichu, B. (2019). An A Priori Measure of Visual Difficulty of 2-D Sketches Depicting 3-D Objects. *Journal for Research in Mathematics Education, 50*(5), 489-528. https://doi.org/10.5951/jresematheduc.50.5.0489

Wright, R., Thompson, W. L., Ganis, G., Newcombe, N. S., & Kosslyn, S. M. (2008). Training generalized spatial skills. *Psychonomic Bulletin & Review, 15*(4), 763-771. https://doi.org/10.3758/PBR.15.4.763

Žilková, K., & Partová, E. (2019). Virtual manipulatives with cubes for supporting the learning process, in International Symposium Elementary Maths Teaching. SEMT'19. In J. Novotna, & H. Moraova (Eds.), *International Symposium Elementary Maths Teaching. SEMT'19. Proceedings* (pp. 427-437). Prague: Charles University, Faculty of Education.