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Training and assessing perspective taking through *A Hole New Perspective*

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***Abstract*—In recent years, the use of Augmented and Virtual Reality (AR/VR) has taken a larger role within training and education of various fields, but not every individual experiences the benefits that AR and VR technology are thought to provide. The perspective taking skill of an individual may be a good indicator of the effectiveness that AR and VR training can achieve. However, we found that the tests in other research targeting small scale perspective taking are few and limited, as perspective taking is often hard to distinguish from mental rotation. Therefore, we designed and developed *A Hole New Perspective*, a serious game created specifically to test and train an individual's perspective-taking ability. *A Hole New Perspective* focuses on the relationship between a 3D object floating in the air and a 2D hole on a moving wall. The core game mechanics consists of having the player rotate the object so that it fits in the hole, before the wall hits the object. Because players do not always have an aligned view with the hole, they have to call on their spatial perspective-taking abilities, in addition to mental rotation. We tested the game with a variety of test subjects, and compared these test results with the Perspective Taking/Spatial Orientation Test. Early results have shown that performance in the game corresponds to mental rotation ability. Furthermore, there are indications that improvement in spatial ability through the game is selectively present for those with lower spatial abilities. This further substantiates the need for a more individualized approach when offering AR and VR in education. Additional training may be needed for some, but not all students.**

***Index Terms*—Serious games, Augmented reality, Virtual reality, Mental rotation, Perspective taking**

I. Introduction

Augmented and Virtual Reality (AR/VR) have been increasingly used for the training and education of students and professionals alike [1], [2]. The use of these technologies allows for individuals to, for example, study difficult maneuvers or complex anatomical structures in great detail. However, people differ very much from each other, and not every individual benefits from these technologies in the same way. In particular, it has been reported that a basic set of skills is deemed necessary for the effective use of VR in educational settings [3], [4]. Among many other skills, the *perspective-taking ability* of an individual may give a good indication of the effectiveness of AR and VR training for that particular individual [5]–[7].

Perspective taking is a skill you acquire and develop from an early age, in everyday life, through many activities, e.g. when playing with Lego's, joining in team sports, and navigating through novel environments. In this paper, we investigate the extent to which a game can help people improve their perspective-taking abilities. For this, we designed a game called *A Hole New Perspective*, in which the player iteratively has to determine how an object can fit through a 2D hole in a wall. The basic game mechanics consists of properly orienting the object, within a limited time, before the approaching wall hits it.

Our main contribution is a novel setup explicitly geared towards promoting incremental perspective taking. It induces the player to take varying points of view on an object, according to both the direction the moving wall is coming from and the shape of the hole in that wall. In other words, the player has to mentally assume the correct perspective regarding the object and rotate it accordingly to fit in the hole.

In addition, we also analyse the player's scores, in order to assess whether they provide a good measure of their progress in perspective-taking abilities. For this, we have to select and perform an established perspective-taking test and compare the player's score in the game with their measured improvement in perspective-taking skills.

II. Related Work

Spatial perspective taking can be categorized into two types: (1) *egocentric* (also known as self-to-object), and (2) *allocentric* (also known as object-to-object) [8], [9]. Egocentric refers to a perspective where the environment is described with respect to ones own point of view, while allocentric refers to a perspective where objects in the environment are perceived with respect to other objects in the environment. For this project, we consider perspective taking as the ability to reason from another object's perspective only, i.e. allocentric, as is often considered crucial for educational purposes in VR [4].

An important spatial skill is the ability to rotate an object to a 'target' orientation. From an egocentric, or observer-based, viewpoint, this problem is often tackled using *mental rotation*. However, this problem can also be approached between two objects, in which case an allocentric, or environment-based, view of the scenario is given, and the individual is required to use their perspective-taking skills to 'act' from the object's location.

TABLE I: Common tests for mental rotation and perspective taking

Test	Description	Skill	Suitable
Van Den Berg Mental Rotation Test [10]	Requires participants to choose which objects are the same under rotational movement instead of mirroring.	Mental rotation	No
Differential Aptitude Test-Spatial Relations [11]	Measures the ability to visualize a three-dimensional object from a two-dimensional pattern, and how this object would look after rotation.	Mental rotation	No
Purdue Spatial Visualization Test [12]	Assesses the ability to recognize the rotation of an object and apply the same rotation to another object.	Mental rotation	No
Mental Cutting Test [13]	Evaluates the capability to identify a projection of a surface after cutting a plane from a three dimensional object.	Perspective taking	No
Perspective Taking / Spatial Orientation Test (PTSOT) [8]	Requires participant to take the position of an object within the environment and look in a specific direction, and then identify the direction to another object.	Perspective taking	Yes

There is a correlation between mental-rotation and perspective-taking abilities. As Hegarty points out, some spatial problems can be solved with both mental-rotation and perspective-taking abilities, even though research has shown the two spatial abilities to be separable [8]. This makes it hard to determine whether a given problem requires mental rotation or perspective taking.

To investigate the extent to which our game is promoting perspective taking, we need to determine a baseline. For this we looked at the most commonly-used tests for perspective taking, and determined which are most suitable to fulfill that role in this project; see Table I.

Van Den Berg [10] describes the Van Den Berg Mental Rotation Test (MRT), which assesses mental-rotation abilities. The test contains multiple-choice questions showing a Tetris shape, with two correct and two incorrect answers: the correct answers depict the Tetris shape in different rotations, the wrong answers depict mirrored images of the shape. There are also other MRT versions available [14], including digital alternatives. Bennett [11] describes the Differential Aptitude Test-Spatial Relations (DAT-SR), which also assesses mental-rotation abilities. The test presents a series of images of the same object, each image applying a fixed rotation to the previous one. The multiple-choice question asks you to pick the answer containing the next image in the series. Bodner [12] describes the Purdue Spatial Visualization Test (PSVT:R), also aimed at assessing mental-rotation abilities. In each question, it shows three images, the second image being the result of applying a rotation to the first one. You are asked to identify that rotation, apply it to the third image, and chose the result from among the given multiple-choices.

The three tests above ask you to identify and/or apply rotations, and are suitable to assess mental-rotation skills. The following tests, in contrast, focus on assessing perspective-taking skills. Quaiser-Pohl [13] describes the Mental Cutting Test (MCT), in which the questions focus on an image of a 3D object. The goal is to identify among the multiple-choice options which ones depict a section cut on the 3D object. Hegarty [8] describes the Perspective Taking/Spatial Orientation Test (PTSOT). All questions focus on an image displaying various objects spread over a 2D plane. For each question, you are told you are at the location of object A (your egocentric point of view) and oriented towards object B; then you are asked at which angle is object C (relative to the line A-B).

Although Mental Cutting Test and PTSOT are both used to assess perspective-taking skills, the Mental Cutting Test uses a cutout view of the object itself, which makes it more fitting for an egocentric, rather than allocentric, approach. In contrast, PTSOT is closer to our allocentric definition of perspective taking, where we want to look at one object from the perspective of another object. For this reason, we decided to use the PTSOT to validate the game score data from our play-test sessions.

III. Game Design

We summarize here the rationale behind the main choices made during the design of *A Hole New Perspective*. These include its core mechanics, various methods of adjusting the game difficulty, and the score mechanism.

A. Core game mechanics

Since we aim to improve the perspective-taking ability of the player, we chose to focus on the relationship between two objects: a 3D object floating in the air and a 2D hole on a wall. The core game mechanics of *A Hole New Perspective* consists of having the player rotate the object, in increments of 90 degrees, so that it fits in the hole. This has to be achieved against the clock, because the wall is moving towards the object. To perform these actions, the player disposes of six controls: two rotations (positive and negative) around each of the three orthogonal axes of the object.

In the first few levels, the player has a front view of the wall and only has to deal with the object rotation, until it fits in the hole; see Figure 1. This initial setup assumes the role of a tutorial, helping the player familiarize with the rotational controls. It provides the player with an egocentric view which, in practice, can be simply solved using mental rotation. The need for actual perspective taking kicks in afterwards, when other types of game levels require an allocentric viewpoint, thus increasing the challenge level, as discussed next.

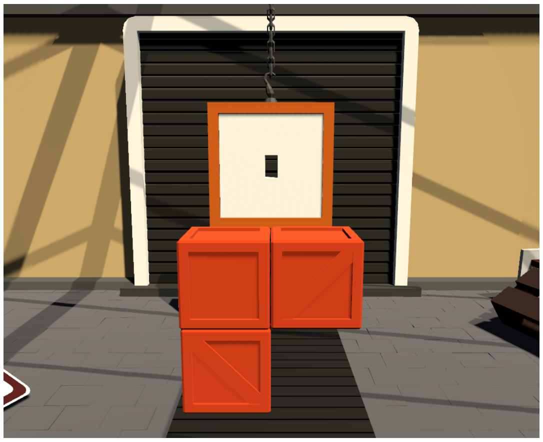


Fig. 1: Basic game mechanics: the object needs to be oriented so as to pass through the hole in the approaching wall.

B. *Difficulty adjustment*

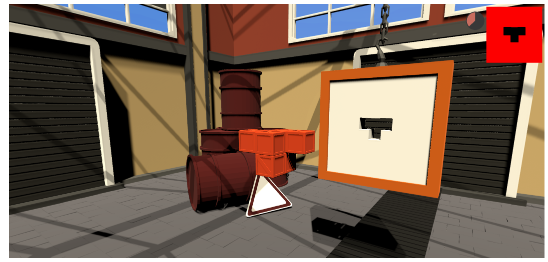
Careful creation of game levels has long been used by designers to challenge players in a gradual manner, as they improve their gameplay-related skills [15], [16]. The level of difficulty in *A Hole New Perspective* can be adjusted in three independent ways: changing the camera viewpoint, varying the complexity of the object shape, and varying the speed of the moving wall.

1) allocentric viewpoints: Changing the camera viewpoint can be done in various ways, but as long as the viewpoint is not aligned with the object and the hole, they all require the player to take an allocentric perspective. In our experience, choosing arbitrary viewpoints can quickly ramp up the difficulty. We therefore chose two fixed viewpoints, shown in Figure 2: the first one takes an angle that is oblique to both the wall movement line and the object axes; the second one is a top view of the object, orthogonal to the wall movement line.

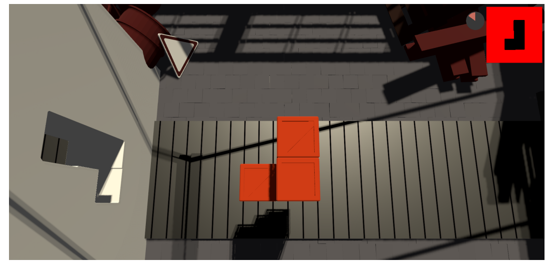
In the latter viewpoint, the start position of the wall, and therefore the hole shape, is not directly visible. In the other viewpoints, in contrast, the hole might get (partially) occluded by the object when they get closer. To overcome either limitation, the player is always shown a small thumbnail of the hole's shape instead (upper right corner of the viewport, in Figure 2).

By assuming these viewing angles on the object and approaching wall, the player needs to imagine the required rotations relative to the object's location, thus effectively taking the object's perspective.

2) shape complexity: Adjusting the complexity of the object's shape is another suitable means to increase the difficulty level. We therefore start with simple objects, with an easy-to-perceive shape, and progressively increase their complexity, basically adjusting both the set of 'building blocks' used to generate them and the ways they may be combined. To maintain variability and prevent memorization, the objects presented are procedurally generated, with a similar difficulty for each game level. The procedural generation method and its controls are described in Section IV.



(a) oblique viewpoint



(b) top viewpoint

Fig. 2: Allocentric viewpoints. The conveyor belt indicates the direction the wall is coming from.

3) wall speed: Besides changing the shape complexity, level difficulty is also controlled by increasing the speed of the approaching wall, thus effectively reducing the time available for perspective taking.

C. *Scoring*

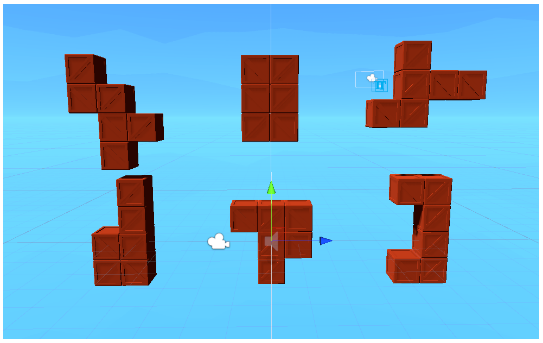
The scoring mechanism has a double purpose: give instant feedback as the player progresses on each level, and provide an indication of the improvement in their perspective-taking skills. For both purposes, and also in order to allow for faster progression, the player can hit the space bar to let the wall abruptly 'drop onto' the object, as soon as they are satisfied with the object's orientation. This convenient feature (inspired by Tetris) rewards fast players with a higher score.

Finally, in order to promote focus and concentration, the player can only make two mistakes in each level, being forced to start it over by the third time that an object does not fit in the hole and gets hit by the wall.

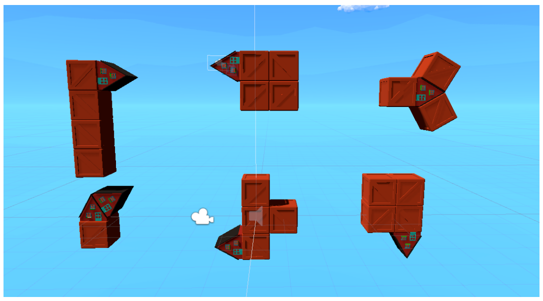
IV. Procedural Object Generation

In many serious games, as is our case, repetition of similar actions plays an essential role [17]. However, you mostly want to prevent solution memory, so that players realize there is no point in remembering details of a particular level's solution. When a combination of customized challenge and novelty is at a premium, procedural level generation is a very common and convenient solution [18].

For *A Hole New Perspective*, we opted for the procedural generation of the object shown at each level. That object is then presented under a randomized choice of orientations, and hence of possible hole shapes, in that level. Besides preventing solution memory issues, such an approach has the additional advantage that we can control the complexity of the

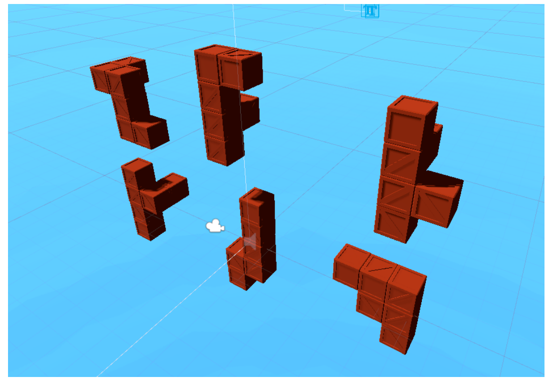


(a) based on cubes

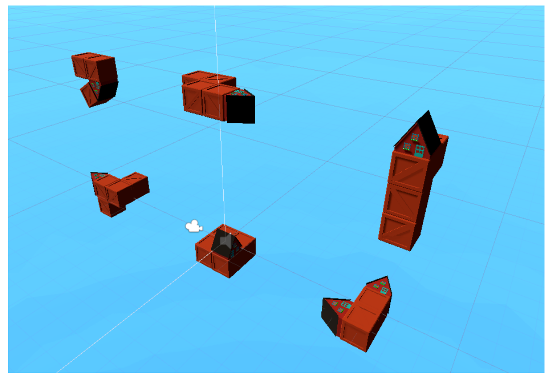


(b) based on cubes and prisms

Fig. 3: Examples of planar objects generated.



(a) based on cubes



(b) based on cubes and prisms

Fig. 4: Examples of volumetric objects generated.

shape generated, effectively allowing for a dynamic difficulty adjustment, following a smooth and adaptive progression over the levels [19]. In this section, we describe the procedural generation method developed for this purpose.

A. Object building blocks

An essential feature of our object generation method is the set of atomic elements, or building blocks, that can be combined. This vocabulary largely determines the expressive power of the algorithm, and the variety of its output. The object generator in the current version of *A Hole New Perspective* uses only two building blocks (a cube and a triangular prism), but the algorithm is completely generic and independent of them.

Using this set as a basis, we devised four groups of objects, with increasing difficulty. The first two groups comprise objects that are all ‘planar’, i.e. all their building blocks lie on the same plane: in the first group, the generator uses only cubes (see Figure 3.a), while in the second group, both building blocks are used (see Figure 3.b).

For the other two groups, we drop the ‘planarity constraint’ above, so that objects consist of building blocks expanding in all three directions. As before, one group uses only cubes (see Figure 4.a), the other uses all building blocks (see Figure 4.b).

In the first few levels, objects from the first group are used, and as the player progresses, objects from subsequent groups are introduced for increased difficulty.

B. Generation algorithm

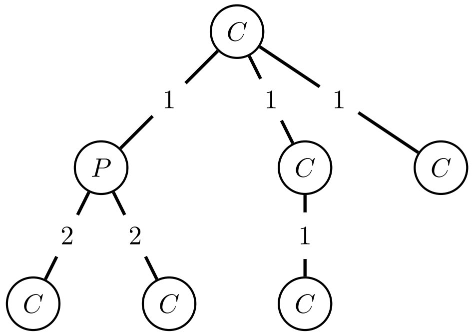
An object is generated by creating a treelike structure, with a building block in each node, to which zero or more child nodes are attached. The root of the tree is represented by a singular starting node (in our case, always a cube). An edge in the tree represents the attachment of a child node. Child nodes can be attached to a parent node using the respective attachment points, which are predefined for each type of node.

Every object generated has a cost defined as the sum of the costs of all the nodes in the tree. The cost of a single node, in turn, is calculated by multiplying its weight with the cost of the parent node (the root has cost 1), and then with the cost of the attachment (the edge) linking them. In order to moderate the complexity of objects, for our game we defined the weight of a cube as 1, and that of a prism as 3. Similarly, the cost of an attachment to a cube is 1, and to a prism is 2. See Figure 5 for an example of an object structure, together with the computation of its cost.

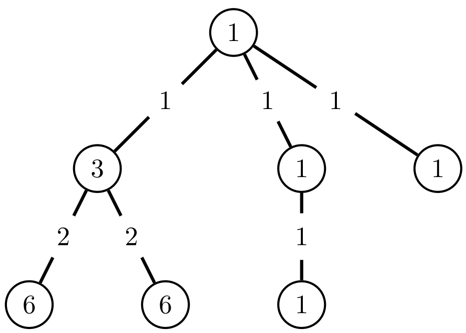
The generation algorithm is controllable in three ways:

- by constraining the set of building blocks used as nodes
- by setting the spatial configurations allowed (in practice, this is done by activating/deactivating the potential attachment points on a building block)
- by adjusting the available budget

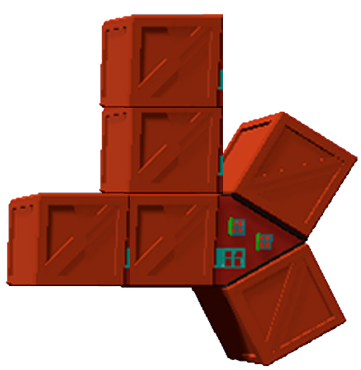
For an object to be successfully generated, its cost has to stay within a given budget, which is used to control termination of the generation algorithm; see Algorithm 1. The selection of an attachment point (step 5) and the extension of the tree with the new node (step 7) are made such as to



(a) Tree structure: C is a cube (weight 1), P is a triangular prism (weight 3).



(b) Cost of nodes; the total structure has a cost of 19



(c) final object

Fig. 5: Example of an object structure

exclude self-intersections.

Note that the object cost itself does not necessarily indicate the difficulty of the object shape, as that is also dependent on the set of building blocks available and on the allowed spatial configuration (planar or volumetric) described before. Yet, it is true that with a low budget, only relatively simple objects can be generated.

The generator allows for the specification of a seed. The object generated after using the same seed will always be exactly the same. This feature is very convenient for the first tutorial levels, in which you want to generate objects of guaranteed simple shapes, for the egocentric viewpoint.

Algorithm 1 object generation on a budget

```
initialize budget
n ← create root node
l ← list of potential attachment points of n
while there is enough budget do
    p ← one random attachment point in l
    m ← create new node within budget
    extend the tree by attaching m to n at point p
    remove p from list l
    extend l with potential attachment points of m
    n ← some random node of the tree
    update available budget
```

V. Evaluation

A. Methodology

Two groups of participants were recruited to examine the relation between the game and cognitive performance. Both groups performed a standardized mental rotation test and the PTSOT. The experimental group played the game in between of the two testing sessions, whereas the control group did not. This experimental design is in line with the aim of the experimental measure, which is to assess the change in performance due to playing the game, in comparison to not playing the game. As mental rotation ability in particular is subject to training [20], a comparison to a neutral control group is more meaningful than only a pre-post comparison within the experimental group. The total sample was constituted of 35 participants from which 17 were males and 18 were females (mean age= 22.69; SD=3.72). The criteria for inclusion and exclusion were: (1) aged between 18 and 30 years old, (2) good understanding of the English language, (3) access to a Windows computer. Before the start of the study, participants provided informed consent.

To measure mental rotation, a modified digital version of The Mental Rotation test was used [14]. The test consists of a total of 24 items that depict a reference figure (left) and 4 figure drawings options (right) that represent either the same target figure rotated to a different angle, or a different figure. Participants were asked to select, as fast and accurately as possible, the 2 out of the 4 figure drawings options that represented the same target figure as the reference. The test was divided into 2 forms of equal difficulty, 12 items in the pre-experimental questionnaire and another 12 items in the post-experimental questionnaire and they had 90 seconds to perform the test for each of the forms. Scores used are the mean score and total number of items performed.

The ability to imagine a scene from a different location in space was assessed through the PTSOT [9]. In this test, participants are asked to indicate the angle to an object (target) while imagining themselves standing at one object facing a second object. Right next to the picture of the array of objects, a circle with 36 equal segments and a line that goes from the centre (object they are asked to imagine themselves standing at) to the top of the circle (object they are asked to imagine themselves facing) is presented. Participants are asked to select the correct segment. This test was also divided into 2 forms with 5 items each and a total time to perform each part of 75 seconds. Scores used are mean deviation and total number of items performed.

The experiment was performed online, using Qualtrics[1]. Participants were asked about their age, gender and gaming experience, and the tasks were presented. Before each task, instructions and practice trials were provided. In the end, we discarded data of one participant, who took over 2 hours to perform the experiment.

B. Results

First, the experimental and control group were compared on demographic characteristics; see Table II. The groups were comparable in age, gender, and mental rotation and perspective taking scores. Gaming experience differed at trend level ($F(1, 32) = 4.15$, $p = .05$, $\eta_p^2 = .115$), with the experimental group having slightly more experience than the control group. Therefore we chose to add gaming experience as a covariate to the performance comparison between groups.

Next, change in cognitive performance was compared between the experimental and control group with an ANCOVA with gaming experience as a covariate. To this end, the pre-game scores were subtracted from the related post-game scores and used as dependent variables. There was no significant difference between the two groups on any of the performance measures; see Table III. However, gaming experience showed to significantly affect the change in mean mental rotation score: $F(1, 31) = 4.35, p < .05, \eta_p^2 = .130$.

Lastly, analyses within the experimental group were performed to assess the relation between gameplay variables and spatial performance; see Table IV. Pearson correlation analyses were performed on the spatial performance scores (pre-game as well as change) and the gameplay variables: number of runs, highest level achieved, total number of correct levels, total number of incorrect levels and total gameplay time. The correlations between the game variables and the spatial performance scores are of primary interest here. The outcome shows that there is a significant positive relation between highest level achieved and mean mental rotation score pre-game, meaning that those with a higher initial level of mental rotation also achieve a higher level in the game. Furthermore, the correlations between pre-game scores and change in scores are of interest. Here, a clear negative correlation between pre-game mental rotation score and both mean score and total number of items is found, which is also visible for the average deviation in perspective taking and mean mental rotation score pre-game. This indicates that those with lower pre-game scores show a significantly larger change in their performance due to the game. A comparable effect was found for the perspective taking mean deviation pre-game: those with larger deviation also have a larger change in mental rotation number of items, as well as a lower change in number of items in perspective taking due to the game.

[1]Qualtrics, version March 2021, © Qualtrics (Provo, UT, USA)

TABLE II: Descriptives of the experimental and control groups on demographics and pre-game spatial performance.

Variable	Experimental group (N=17)	Control group (N=17)
Age (in years)	21.7 (3.5)	23.5 (3.8)
Gaming experience	2.82 (1.29)	2.00 (1.06)
Mean MR score pre-game	0.68 (0.31)	0.71 (0.37)
Total items MR pre-game	4.41 (2.92)	5.06 (3.23)
Total items PT pre-game	3.71 (0.92)	3.65 (0.93)
Average deviation PT pre-game	2.58 (2.96)	4.31 (6.03)

SD in parentheses, MR=mental rotation, PT=perspective taking

TABLE III: Change in spatial performance of the experimental and control groups (post-game score – pre-game score)

Post-game – pre-game score	Experimental group (N=17)	Control group (N=17)
Mean MR score	-.03 (0.38)	0.12 (0.32)
Total items MR	0.71 (2.52)	0.73 (2.40)
Total items PT	0.41 (0.84)	0.73 (0.88)
Average deviation PT	1.32 (2.24)	1.06 (2.93)

C. Discussion

The findings of the evaluation study indicate that in its current form, the game does not lead to immediate changes in cognitive performance. However, the results indicate that the game is closely linked to the cognitive domains of mental rotation. Those who have a stronger mental rotation ability before playing the game, will proceed to reach a higher level within the game. This suggests that the game makes use of mental rotation ability. Related to this finding, in a more general sense, we observed that gaming experience is related to a higher mental rotation performance.

In this evaluation study, the sample size may have been too small to observe immediate impact of gameplay, and the playing session may likely need to be longer to achieve clear cognitive improvement. The perspective-taking elements in the game were introduced after sufficient training in the levels that entailed mental rotation, and only 7 out of 17 participants in the experimental group did not reach the levels that included the perspective changes. As perspective taking is added only after progression through the game, players differ in the number of levels including perspective taking, which may hinder the hypothesized training effect. In its current form and use, the game primarily addressed mental rotation ability. With prolonged gameplay and/or an earlier introduction of perspective taking levels, the impact of training on perspective-taking performance may be stronger. Moreover, we find that the lower the initial mental-rotation performance is, the larger the change in spatial performance is after playing the game. This supports the notion that the game may selectively benefit those with lower levels of initial cognitive performance. The pattern is less clear for the perspective-taking measures, possibly due to the method of administration, which was online. In a supervised lab setting, the quality of perspective-taking measurements would likely be better due to task complexity and offering materials in a three-dimensional setting.

VI. Conclusion

Perspective-taking abilities are demanded by the increasing use of Augmented and Virtual Reality technologies, particularly in educational contexts. We presented *A Hole New Perspective*, a game explicitly designed to train and develop these abilities in the player.

A Hole New Perspective is focused on both mental rotation and perspective taking abilities. In the initial levels solely mental rotation is necessary, and perspective taking is added as the player progresses in the game. The results indicate that the training, in its current format, does not lead to an improvement in either mental-rotation or perspective-taking ability. However, the data do support that *A Hole New Perspective* makes use of mental-rotation ability in particular. Furthermore, the findings substantiate earlier reports on the shared cognitive characteristics of mental rotation and perspective taking.

For future research into the game effectiveness several improvements should be considered. First and foremost, a more elaborate training, with additional training sessions and more perspective-taking levels is expected to lead to a stronger impact on cognitive performance. Given the complexity of perspective taking, a more supervised administration of the pre- and post-game tests are expected to enhance the quality of the measurements. Furthermore, the results of the game evaluation highlight the role of individual differences. The game may specifically benefit those with weaker initial spatial skills. A larger sample of participants, incorporating such individual variation may be informative in understanding the cognitive impact of playing *A Hole New Perspective*.

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TABLE IV: Correlation coefficients within the experimental group for the gameplay measures, pre-game spatial performance scores and change in spatial performance scores (post-game score – pre-game score)

	Number of runs	Highest level	Correct levels	Incorrect levels	Gameplay time	Mean MR pre-game	Total items MR pre-game	Total items PT pre-game	Average deviation PT pre-game	Mean MR change	Total items MR change	Total items PT change
Number of runs												
Highest level	NS											
Correct levels	NS	NS										
Incorrect levels	NS	NS	NS									
Gameplay time	0.733*	NS	0.527*	NS								
Mean MR pre-game	NS	0.562*	NS	NS	NS							
Total items MR pre-game	NS	NS	NS	NS	NS	NS						
Total items PT pre-game	NS	NS	NS	NS	NS	0.512*	0.491*					
Average deviation PT pre-game	NS	NS	NS	NS	NS	-0.505*	NS	NS				
Mean MR change	NS	NS	NS	NS	NS	-0.782**	NS	NS	NS			
Total items MR change	NS	NS	NS	NS	NS	-0.534*	-0.697**	NS	0.553*	NS		
Total items PT change	NS	NS	NS	NS	NS	NS	NS	NS	-0.587*	-0.630**	NS	
Average deviation PT change	NS	-0.561*	NS	NS	NS	-0.593*	NS	NS	NS	0.369	NS	NS

NS=not significant; *$p < .05$; **$p < .01$