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An Experimental Study of Perception by Preschoolers: The Computer Models of Real Objects as Three-Dimensional on the Screens of Touchscreen Devices

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ABSTRACT
The experimental study presented in the article is the first in our series of experiments aimed at testing the hypothesis that children rely on the characteristics of real physical objects known to them when they perceive computer models of these objects (virtual objects). The dimension was chosen as the first investigated characteristic. Dimension is an amodal characteristic, that is, it can be perceived on the basis of sensory information of various modality (visual or haptic). A pilot experimental study was conducted to test the hypothesis: do children of preschool age perceive virtual three-dimensional objects as three-dimensional when acting on them on a tablet computer screen (on a two-dimensional surface).
The experiment was attended by 20 children aged 4-5 years. Each child participated in five experimental tests: the main test 1 - actions (moving by touching) with a virtual volumetric object on the tablet computer screen, sample 2 - viewing the image of a volumetric object on the tablet computer screen without performing actions with it. Three additional tests with real volumetric objects (visual, haptic, visual-haptic) were also performed to assess the perceptual development of children. After each test, the children were offered, on the basis of only haptic information, to choose a reference object among four objects: two three-dimensional and two flat. 94.1% of children who successfully identified real objects identified the virtual object after sample 1 as three-dimensional, despite the effect of the mismatch between visual and haptic information. The results are consistent with the idea of the optimal integration of visual and haptic information in the perception of the size and shape of three-dimensional objects by giving more weight to more reliable information.
In sample 2, in the absence of the possibility of action with the image on the tablet computer screen, the number of errors associated with the recognition of a virtual three-dimensional object as three-dimensional significantly increased (33.3%).
Keywords: *virtual 3D images, visual-haptic perception, visual-haptic discrepancy*

1. INTRODUCTION

Many researchers point to the specifics of the situation of cognitive development of modern children, which is determined by the use of computer devices (CD) already in infancy and early childhood. The lack and inconsistency of the results of precisely psychological studies of the phenomena associated with this situation is also noted [1]. Despite the large number of psychological publications devoted to human interaction with the digital environment, most studies focus on the study of CD themselves as tools used to carry out specific activities. This approach defines several areas of research: 1) the study of the characteristics of activities carried out directly with CD (for example, the duration and frequency of use of the CD; use of the CD to solve various educational problems); 2) the study of activities in a virtual environment created by CD (for example, information and psychological security; means of communication in social networks); 3) the study of the characteristics of the subject of activity (for example, digital identity; motivation for using digital devices; various types of computer addictions).
The results obtained certainly expand the scientific understanding of human interaction with the digital environment. However, we believe that if children of early and preschool age are considered as subjects of such interaction, it is necessary to shift the focus of research. This shift, in our opinion, is based on the assumption that children of early and preschool age interact not so much with CD itself (similar to how they interact with other objects-tools), but with virtual reality created using this device. From this point of view, the subject of study should be the process of children's cognition of virtual reality, including the characteristics of objects of this reality (virtual objects). In relation to children of early and preschool age, we will first of all discuss such a kind of

virtual reality as non-immersive virtual reality, believing that interaction with immersive and augmented virtual realities is characteristic of older age groups.

1.1. Perception of the characteristics of a virtual environment and virtual objects

In scientific publications, the perception of characteristics and objects of a virtual environment more often appears not as an independent subject of research, but as an element of an experimental situation for studying the laws of "real" perception (that is, perception of objects of a real environment carried out by people in their daily lives and activities). Modeling a virtual environment allows us to separate the studied independent variable from side effects and provide more stringent control of variables, which is not always possible to do in real conditions. In published studies, the subject's perception of the testee was such properties of virtual objects and virtual environment as the length of a virtually simulated distance traveled [2], the length of objects [3], size [4], stiffness [5], texture [6], depth [7] , weight [8]. The goal of many studies, including subjects' reports on perception in a virtual environment, is to develop technologies to bring the perceptual characteristics of the virtual environment closer to the real one, to make the boundary between these environments "invisible" [7], [9]. It was shown that, using a special optical device, it is possible to provide a ratio of the depth and size of virtual objects corresponding to this ratio for real objects, and thus increase the realism of the visual perception of virtual objects [7]. The use of tactile feedback devices installed on the finger, which deform the skin at the fingertips, allows users to feel the difference in the weight of a virtual object [9]. Creating a visual delay when modeling the process of lifting a virtual object makes participants perceive virtual objects as heavier than when performing lifts without visual delay [8]. Summarizing the results of the considered experiments, the following can be noted: 1) the participants in the experiments were adults, whose perception was formed in the conditions of interaction with real objects (which distinguishes them from modern children); 2) the purpose of the experiments is to determine the conditions under which the perception of the virtual environment will not differ from the perception of reality; 3) the use of additional devices allows you to control the perception of virtual objects, creating the illusion that they have the properties of real objects.

1.2. The effect of visual-haptic inconsistency in the perception of virtual objects

Many researchers have noted such a feature of the perception of virtual objects as the lack of realistic haptic / tactile feedback. Indeed, in contrast to the perception of real objects, which is based on information of various sensory modality, the perception of virtual objects is carried out mainly visually. Moreover, actions with virtual objects on the screen of touch-screen devices are simple and identical for objects of different shapes and textures, since they are carried out in the form of movements with one / two fingers on a flat surface of the screen. The tactile information obtained in this way conflicts with the visual information.

In scientific publications, various concepts are used to describe the effects associated with the mismatch of sensory information of various modalities: visual-tactual incongruity [10], the lack of realistic haptic feedback [9], visual-tactual discrepancy (visual-tactual discrepancy) [4], [11], multisensory conflict (multisensory conflict) [12].

The experiments carried out provide a variety of information about the effect of the mismatch between visual and haptic information when perceiving real and virtual objects for groups of subjects of different ages. Studies in the field of product design showed that when assessing real objects with sensory inconsistencies (visual-tactual, visual-olfactory, and visual-auditory), participants experienced emotions of surprise and embarrassment, the intensity of which depended on the degree of relevance of the inconsistencies [10]. In a study [11], the behavioral responses of 11-month-old infants to visual- tactual imbalances created by mirror placement were studied. Based on the results obtained, it was concluded that texture and shape can serve as the basis for cross-modal correspondence, and visual information plays a guiding role for the manual research actions of infants. A study of perception in a multisensory conflict modeled both in real conditions [13] and in immersive virtual reality [12] allowed us to conclude that the brain tends to integrate visual and tactual information, giving more weight to more reliable information.

Our study is the first in our planned series of experiments aimed at studying preschoolers' knowledge of the characteristics of virtual objects. Since virtual objects are visually exact replicas of real objects, it can be assumed that children will attribute to the virtual objects the characteristics they know of real physical objects. The dimension was chosen as the first investigated characteristic. Dimension, like volume, is an amodal characteristic, that is, it can be perceived on the basis of sensory information of various modality (visual or haptic). Virtual three-dimensional objects are visually perceived as voluminous, while actions with them on the screen of the touchscreen device (movement, rotation) are carried out in the plane, which creates the effect of a mismatch between visual and haptic information.

We conducted a pilot experimental study aimed at testing the hypothesis: do children of preschool age perceive virtual three-dimensional objects as three-dimensional when acting on them on a tablet computer screen (on a two-dimensional surface).

2. METHODOLOGY

2.1. Subjects /Субъекты

The study involved preschool children with the normative development of visual and motor-moving functions. The experiment was attended by 20 children, aged 4-5 years, kindergarten pupils.

2.2. Stimuli and Apparatus

To implement the experiments, experimental equipment was prepared - a special closed box with opaque walls, with an opening for manipulating with one hand. The back wall of the box was removed, which allowed the experimenter to observe and record the haptic actions of children.
The use of equipment made it possible to exclude the possibility of children's visual perception of objects in the box.
In each experiment, four specially made “new” (non-repeating) objects were used as stimulus material. These objects were made in such a way that they did not look like real objects known to children and used by them in their daily lives. This was done in order to exclude the transfer of the properties of objects familiar to children to stimulus material.
In each series, one object was conditionally called a "reference", the remaining three - distractor objects. The reference object was presented to the subject for review, and then it was necessary to “find” it in a special closed box using haptic perception. All reference objects were three-dimensional, had a complex three-dimensional shape and curvature. Distractor objects differed from the reference one either by the absence of one part or by dimension: one of them was three-dimensional 3D (like the reference object), and the other two were flattened and had a contour (they were not two-dimensional 2D in the full sense of the word, because they had approximately 0.8 cm thick). Distractor objects increased the difficulty index of the task, but did not reduce the distinguishing ability of the task (discriminativity).
All objects were approximately the same size, made of the same material (polymer clay). The size of the objects implied the ability for the child to hold (grab, grasp, touch) the object with one hand, that is, without much effort to implement haptic perception

2.3. Procedure

The experiment involved five experimental tests: (1) the main “virtual with the possibility of action (computer model)”, (2) the control “virtual with the possibility of action (photo)”, (3 - 5) additional tests (“visual”, “haptic”," Visual-haptic ").
Form of conduct - individual game classes. Each child participated in all five experimental trials.
Before the experimental tests, the experimenter made contact with the child in a playful way, introduced him to the material - polymer clay, demonstrated methods of haptic contact with objects.
Further, all experimental tests were carried out according to a single algorithm.
The first stage is “getting to know the standard”. The child was offered instructions for familiarizing himself with the object (depending on the task of the experimental test).
The second stage is the "training". After acquaintance with the object, the test subject was presented with stimulus material (objects made of polymer clay) and offered, using exclusively haptic actions, to feel these objects inside the special box without visual control. At this stage, the child was not limited in time. The movements associated with the examination of the object were also not limited in any way, which allowed the subjects to choose the most effective haptic perception strategy.
The third stage is “actually experimental”, where the child performed the experimental task of haptic recognition of the reference object, making a choice of four objects (one - reference, three - distractors). The experimenter's assistant recorded two parameters: the correctness of the task (true / false) and the time from the start of the haptic recognition action to the end of the task (the execution time was indicated in seconds in the protocol).
To prevent the formation of the effect of training the haptic recognition of objects, a series of experimental samples were presented to children in turn.
Let us briefly describe each of the experimental samples.
Experimental probe 1
In the first experimental test - the main “virtual with the possibility of action (computer model)” - the child was asked to view and “rotate” on the tablet computer screen a virtual model of a three-dimensional object of complex shape (Fig. 2).

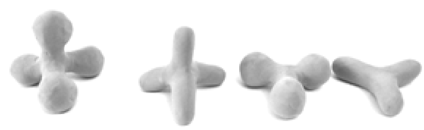

Figure 1 Stimulus material for the main experimental test “virtual with the possibility of action (computer model)” (reference object - leftmost)

Figure 2 Computer model on tablet computer screen

The virtual model could be rotated about the vertical and horizontal axes. The rotation movement involved touching the screen with a finger and making a “sliding motion” in the two-dimensional space of the screen plane.

For the first experimental test, an application was developed that allows the child to manipulate three-dimensional models on the screen of a tablet computer. To implement this idea, a 3D model of the required object was created using the Blender package. The choice of the Blender program as an editor for creating three-dimensional computer graphics was determined by the availability of modeling, sculpting, animation, simulation, rendering tools, as well as the availability of technical support and open source code. The three-dimensional model created by Blender was imported into the application. Since it was originally planned to operate the application running the Android operating system, the Java programming language containing the necessary tools was chosen to create it. When developing the application, the LibGDX framework was used, designed to create cross-platform games and applications. All selected tools belong to non-proprietary software, which allows you to freely use it for educational and scientific purposes.

This was followed by the training stage, during which the child performed haptic actions (touching, sweeping, rotating, lifting, etc.) without visual control with four objects in a special box. One of these objects was a copy of the object model depicted on the tablet computer, the other three were distractor objects.

After the haptic perception of objects without visual control, the child was asked to find the object that he saw on the screen of a tablet computer and say that the figure was found.

Experimental probe 2 / experimental probe 2

***In the second experimental test (control)* -** “virtual without the possibility of action (photo)” - the child was asked to look at the tablet computer screen image (photograph) of a three-dimensional object (Fig. 4). The size of the image in the photograph corresponded to the size of the real reference object and distractor objects. Unlike the main experimental test, the child did not perform any actions with the image on the tablet computer screen. This was followed by the "training phase", and after - "actually experimental."

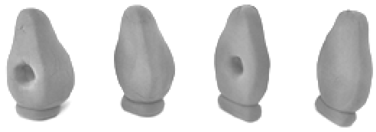

Figure 3 Stimulus material for the main control sample “virtual without the possibility of action (photo)”

Figure 4 Photo on tablet screen

We describe additional experimental tests that were implemented to assess the level of perceptual development.

Experimental probe 3

In the third experimental test - “visual” - the child was asked to consider a real three-dimensional object, but without the possibility of its touch (the object was under a special glass dome). Then, as in previous experimental tests, the “training” and “experimental” steps followed, which culminated in the task of recognizing the reference object.

Experimental probe 4

In the fourth experimental test - “haptic” - the child was asked to take an object with one hand, to perform any haptic actions (touch, rotate, hold, twist, etc.) without visual control. The object was placed in an opaque cloth bag. Then followed the "training" and "actually experimental" stages.

Experimental probe 5

In the fifth experimental test - “visual-haptic” - the child was offered to take a real object with both hands, perform any haptic actions (touch, rotate, hold, twist, etc.) with visual control (examining the object). This was followed by the "training" and "actually experimental" stages.

Figure 5 Stimulus material for experimental additional tests 3-5

3. RESULTS

During the implementation of all experimental samples, the following indicators were recorded: "success in completing the task", "dimensional error", "shape error", "time to complete the task."

By "success" we understood the correspondence of the selected object (recognizable haptically) to the presented (reference) object, regardless of the presentation conditions (virtual model; photograph; visual perception without the possibility of haptic recognition; haptic perception without visual control; and multimodal haptic and visual perception at the same time).

We took into account two types of errors: dimensional errors — recognition of a three-dimensional reference object as two-dimensional; shape errors - recognition as a reference object, which lacked some details compared to the reference (for example, thickening at the ends or hole). The results for parameters reflecting the success and type of errors are presented in Figure 6.

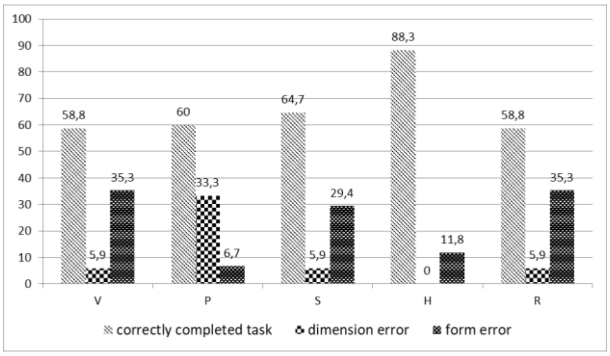

Figure 6 Distribution of success indicators and types of errors in five experimental samples

Note to Figure 6: letter designation of experimental samples:

V - "virtual without the possibility of action (computer model)", P - "virtual without the possibility of action (photo)", S - "visual",

H - "haptic", R - "visual-haptic".

The histogram data indicate that the success of haptic recognition of objects in the main and control experimental samples has no statistically significant differences ($\varphi_{эмп}$ = 0.039, at $p \geq 0.05$). 58.8% and 60% of respondents correctly recognized the reference object.

In the first main experimental test "virtual with the possibility of action (computer model)", children made a significantly smaller number of dimensional errors (5.9%) compared with the second control test (33.3%) ($\varphi_{эмп}$ = 2.08 at p = 0.018) At the same time, shape errors (35.3%) turned out to be more characteristic for the main experimental sample ($\varphi_{эмп}$ = 2.11 at p = 0.017). In additional experimental samples ("visual" and "visual-haptic"), there are no significant differences in the number of errors of both types with the main experimental sample ("virtual with the possibility of action (computer model)").

When completing the task of the fourth "haptic" test, the children made no dimensional errors, that is, they perceived the object as three-dimensional. Also, this test is characterized by the highest recognition success rates among additional samples.

A comparative analysis of the length of time (fraction of time) spent on the task (finding the standard) in different experimental samples was carried out. The histogram (Fig. 7.) shows the graphs of the time duration (fraction of time) in the main and additional experimental samples.

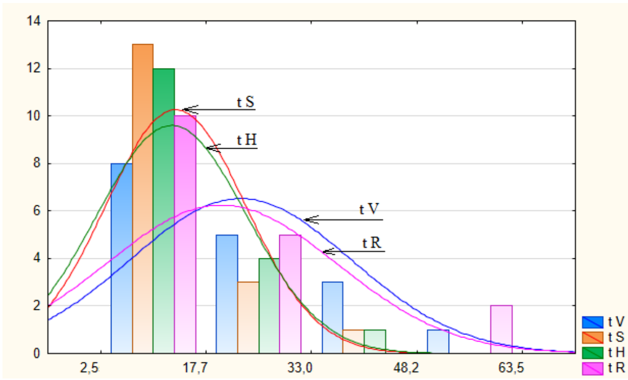

Figure 7 Distribution of time duration (fraction) for recognition of a reference object in the main and additional experimental samples

The histogram shows that the proportion of time to complete the tasks of the main experimental series and the additional "visual-haptic" is significantly greater than the same indicator in the additional "visual" and "haptic" experimental samples.

4. DISCUSSION

The results obtained in the main experimental sample 1 indicate that the proportion of dimensional errors was 5.9%. Thus, when 4-5 year old children were able to perform the rotation of a virtual object on the screen of a tablet computer, 94.1% of them correctly identified this object as three-dimensional, despite the mismatch between the haptic and visual information about the object. This result is consistent with the results of studies of perception in a multi-sensory conflict [12], [13], according to which the brain seeks to integrate visual and tactile information, giving more weight to more reliable information. Apparently, the visual information in this case was more reliable for children. Confirmation of the important role of visual information can be the results of studies of infants under conditions of visual tactile discrepancy, which confirm the guiding role of visual information for the manual research actions of infants [11]. Also, our result can be considered as consistent with the conclusions that the concept of space (as well as the concept of objects and actions) is one of the primary cognitive structures that form in infancy (towards the end of the first year of life) and allow infants streamline a diverse sensory experience [14]. Thus, by the age of 4, children have already formed an idea of a real three-dimensional space, which organizes the process of perception of any objects, including virtual ones.

In control experimental test 2, when children could only visually perceive a photographic image of a three-dimensional object on the tablet computer screen, but were not able to perform actions with it, the proportion of dimensional errors increased to 33.3%, which is statistically significantly larger than the proportion of these errors in sample 1 ($\varphi_{эмп}$ = 2.08 at p = 0.018). The inability to rotate the image of the object leads to a decrease in the bandwidth of the visual channel, limiting the spatial bandwidth to only one projection of the object in the plane of the screen, which complicates its further recognition ([15], cited in [16]).

In order to exclude the assumption of insufficiently obvious visual representation of the three-dimensionality of the photographic image, we conducted a control sample 2 additionally on a sample of 15 students (18-20 years old). A 100% success rate of recognition of the reference object was obtained. Thus, the visual details indicating the three-dimensionality of the depicted object (the presence of shadow, image width) turned out to be uninformative for 33.3% of children 4-5 years old.

At the same time, it should be noted that when performing the main experimental test 1, the children made a lot of shape errors associated with overlooking the details of the object. The proportion of shape errors was 35.3%. As you know, with visual perception of an object without special training (or instruction) for preschoolers aged 4-5 it is difficult to differentiate the details of the object. Therefore, in a situation of observing a new object or phenomenon, children need to pronounce those details of the object that they need to pay attention to. In the absence of such instruction or special training, even essential details may not fall into the spotlight and not be fixed by the child - he will not notice them and will not remember them in the future.

In control experimental sample 2, the number of shape errors turned out to be significantly smaller (6.7%) compared to the same indicator in sample 1 (35.3%) ($\varphi_{эмп}$ = 2.11 at p = 0.017). Perhaps this is due to the smaller number of expressed details of the reference object in sample 2, that is, it is an instrumental effect.

Analyzing the correlation of errors of both types and success rates in various experimental samples, it can be seen that, by the ratio of errors, the results of experimental sample 1 are closest to the results of additional visual-haptic sample 5 (Fig. 6). The share of time spent on the recognition of the reference object in these two samples turned out to be significantly more than the share of time spent in other samples (Fig. 7). This difference may be due to the fact that in samples 1 and 5, object recognition is based on information from two sensory modalities - visual and haptic, while in other samples - on the basis of one (either visual or haptic).

The smallest number of errors was noted for the haptic test 4: dimensional errors - 0%, shape errors - 11.8%. For this sample, the fraction of time spent on object recognition is also the smallest in comparison with samples 1, 2, and 5. We believe that this is due to the fact that the presentation and recognition of the reference figure was based on the same sensory modality

5. CONCLUSION

The results of the pilot study allow us to draw the following conclusions:

1. 94.1% of children 4-5 years old perceive computer models of three-dimensional objects on a tablet computer screen (virtual objects) as three-dimensional (3D) despite the discrepancy between the visual and haptic information about these objects obtained by performing actions on them on a two-dimensional screen surface . Although the sample size is limited, it can be assumed that an increase in the sample will confirm the result, since the dimension of space is one of the fundamental characteristics, the perception of which is formed in infancy.

2. When perceiving virtual objects in the process of carrying out actions with them on the tablet computer screen, children 4-5 years old make mistakes in recognizing the shape of objects (35.3%). These errors are associated with difficulties in recognizing the number and shape of parts of objects. However, errors in shape recognition are not related to the “virtuality” of the object, since children made similar errors in the visual (29.4%) and visual-haptic (35.3%) perception of real objects.

3. In the case when children do not have the ability to carry out actions with the image of a three-dimensional object on the screen of a tablet computer, they more often

perceive this object as two-dimensional (33.3% of children).
The results can serve as additional arguments for recommendations to abandon the use of computer touchscreens by infants until they have formed primary cognitive structures for perceiving the basic characteristics of the real world [1].

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