"BABEȘ-BOLYAI" UNIVERSITY CLUJ-NAPOCA
FACULTY OF PHYSICAL EDUCATION AND SPORT
DOCTORAL SCHOOL

SUMMARY OF THE PH.D. THESIS

Scientific Supervisor:

Prof. Univ. Dr. Emilia Florina GROSU

Ph.D. candidate:

Ștefan MOROȘANU

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Improving reaction time and hand-eye coordination in 17-19 year old students using virtual reality

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Keywords: virtual reality, exergames, psychomotricity, Head-Mounted Display, neuroplasticity, quality of life, immersive, coordination, reaction time

Abbreviations

CAVE – Cave Automatic Virtual Environments

HMD – Head Mounted Display

CNS – Central Nervous System

PNS – Peripheral Nervous System

VR – Virtual Reality

List of publications

Moroșanu, Ș. & Grosu, V., T. (2022). Using Virtual Reality for Motor and Psychomotor Skill Development: A Systematic Review. *The 8th International Conference of the Universitaria Consortium (ICU)*, 297-305, Cluj-Napoca.

Răbâncă, S., M., Moroșanu, Ș., Grosu, V., T. (2022). Pulmonary Rehabilitation Through Physical Exercise – An Essential Factor Regarding Patient Recovery In A Post-COVID-19 World. *Gymnasium -Scientific Journal of Education, Sports, and Health, 23* (2). DOI: https://doi.org/10.29081/gsjesh.2022.23.2.01

Moroșanu, Ș., Răbâncă, S., M. , Rusu, A., C. Martinovici, M. (2023). Improving reaction time and hand-eye coordination in high school students using virtual reality: A Pilot Study. *Science, Movement and Health, 23* (2): 208 – 212. https://openurl.ebsco.com/EPDB%3Agcd%3A14%3A21839806/detailv2?bquery=AU%20Rusu,%20Alina&page=1

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Introduction

We are in a period of human history where technology is at every turn. Most children and teenagers spend most of their free time playing various games on their phone, computer, Playstation or other cutting-edge devices.

Although most studies blame these behaviors, being considered among the main causes of sedentary behavior among children and adolescents, we aim in our study to check if we can use technology as a double-edged sword and positively influence the quality of life of those mentioned above through it.

The consequences of video games have been a hotly debated topic in recent decades. While the media tends to focus on and publicize the supposed negative effects of video games, the empirical literature continues to research to illustrate the benefits of playing certain types of video games, in particular, active video games (Glueck & Han, 2019).

New alternatives to exercise can help people commit to a healthier lifestyle. Transforming sedentary video games into active games (exergames) could increase caloric expenditure and also improve coordination, reaction time, and athletic skills, thus replacing sedentary behaviors (Trost et al., 2014; Çakmakçı et al., 2019).

The emerging technology of virtual reality (VR) gives us an opportunity to explore how to better engage people with health messages and apply this innovative method to promote healthy behaviors and advance new theories (de Back et al., 2020; Aulisio et al., 2020).

We believe that reaction time and hand-eye coordination are two of the psychomotor skills that influence the level of involvement of students in motor activities. According to the results of a 2014 study, a high level of objectively measured moderate or vigorous physical activity was associated with good performance on the reaction time test, which measures subjects' reaction time and speed of response to a visual target (Syväoja et al., 2014).

Through this work we want to highlight the usefulness of virtual reality technology for improving reaction time and hand-eye coordination and the importance of these psychomotor skills for the involvement of high school students in organized motor activities.

Part I – Theoretical Framework

Chapter 2. Physical Activity, Virtual Reality and Exercise in the Virtual Environment

2.1. Physical Activity

Technology such as video games play a complicated role in physical inactivity. Traditionally, video games have contributed to the physical inactivity epidemic by being blamed for individuals' sedentary lifestyles. On the other hand, newly emerging active video games have been increasingly used to promote physical activity and health among different populations. (Huang et al., 2017; Vaghetti et al., 2018).

In short, active video games refer to video games that are also a form of exercise (Benzing & Schmidt, 2018).

A US study showed that active video games included in a weight management program led to significant increases in moderate to vigorous physical activity among overweight and obese children. The introduction of active games resulted in an additional 7.4 min/day of moderate to vigorous physical activity. In contrast, participants who were assigned to the usual 16-week weight management program without active video games showed little or no change in physical activity (Trost et al., 2014).

Virtual reality through specific means - exergames or active video games, as they are also called, can be used as physical exercises and can represent a means to improve psychomotor skills and increase the physical activity of subjects (Gao & Chen, 2014). It has proven to be an enjoyable activity for teenagers, young adults and older (Adachi & Willoughby, 2015).

One cause of sedentarism is the lack of confidence in the abilities to practice a certain sport. For example, a child less talented at football will be reluctant to practice this sport later when he notices that his abilities are inferior to other children.

Interestingly, playing sports video games may be associated with higher levels of real-life sports involvement. For example, teenagers who play sports video games can find fun in them, learn the rules and strategy of various sports, and also experience the thrill of victory, thus increasing the chances of being involved in various sports in real life as well. (Adachi & Willoughby, 2015).

2.2. Virtual Reality

In the Oxford online dictionary, virtual reality (VR) is defined as "the computer-generated simulation of a three-dimensional image or environment that can be interacted with in an apparently real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves equipped with sensors."

Virtual reality is also defined as "the three-dimensional digital representation of a real or imaginary space with interactive capabilities" (Zyda, 2005).

Currently, standard virtual reality systems generate realistic images, sounds, and other sensations that simulate a user's physical presence in a virtual environment.

In the many applications of virtual reality, the authors propose that the main part of this technology is to cognitively transport the user into a digital environment (Burdea & Coiffet, 2003). The concepts of fidelity, immersion and presence become essential when discussing virtual reality (Howard, 2018; Jensen & Konradsen, 2018).

Fidelity refers to the similarity of the virtual environment and/or tasks to the real environment. The greater the similarity, the higher the fidelity.

Immersion in virtual reality is the perception of physical presence in a non-physical world. Perception is created by surrounding the user of the VR system with images, sound or other stimuli that provide a highly immersive environment (Freina & Ott, 2015).

Full immersion in a virtual environment comes via a "Head Mounted Display" (HMD) or using a "Cave automatic virtual environment" (CAVE) and can even include haptic interface devices (hand controllers and joysticks) that allow users to interact with the virtual environment.

HMD is a wearable device that covers the eyes and thus removes the view of the outside world. It has two small screens through which the virtual world is viewed, it is also combined with head and hand tracking. As a smaller, more portable and more affordable system, the HMD is more popular than the CAVE, although both can be considered to share the same key characteristics of an immersive system (Neumann et al., 2018; Amprasi et al., 2021).

This new technology is increasingly applied in various areas of life, with most studies focusing on the medical field, especially in rehabilitation (Levac et al., 2019; Buettner et al., 2020) and in the educational field (Hamilton et al., 2021).

However, in addition to medicine, other disciplines such as psychology, sports science, neuroscience or computer science are involved in the research of active video games, showing the interdisciplinary nature of this medium (Glueck & Han, 2019).

2.3. Exergames – Exercise in the Virtual Environment

For years, researchers have studied exercise and the various effects it has on the human body. Exercise is known to help with weight management, improve mood, motor ability, and cognitive processing (Manno, 2008).

Virtual reality through specific means - exergames or active video games, as they are also called, can be used as physical exercises and can represent a means to improve psychomotor skills and increase the physical activity of subjects (Moglia et al., 2016).

In addition to the already known effects of physical exercise, exergames would increase the brain's adaptive potential, a phenomenon known as neuroplasticity, which would result in improved problem-solving ability as well as greater sensorimotor integration (Dye et al., 2009).

There is no universal definition of exergaming available. According to Bogost (2007) exergaming has been labeled by the media as "the combination of exercise and video games". Although this description is used by both commercial industry and science, it does not serve as an adequate formal definition. This becomes apparent when we adhere to the traditional definition of "exercise" as consciously and systematically accomplishing certain stated goals, according to which many available exergames (eg, those with alternative intentions than improving fitness) would be excluded (Bogost, 2007).

Exergames are computer games that use motion-sensing technology that reflects the player's body movement on the screen and thereby allows them to control virtual characters (Huang et al., 2017). Exergames are video games that require participants to engage in physical movement to play, they are video games that combine entertainment and body movement (Sheehan & Katz, 2013).

Exergames can now track full-body movement in three dimensions, accurately measure reaction time and acceleration, and capture the speed and power of a player's movement (Mokmim & Jamiat, 2021).

Exergames differ from sedentary video games because of the physical effort and physical capabilities required to play the game. Many exergames stimulate auditory and visual reaction time and hand-eye coordination. However, exergames also require other physical capabilities such as aerobic endurance, strength, balance and flexibility to support the gameplay and narrative of the games (Vaghetti et al., 2018).

Properly structured, dosed and planned this form of physical exercise practice could be a viable option for improving psychomotor skills.

Chapter 3. Psychomotricity, Reaction Time and Hand-Eye Coordination

3.2. Reaction Time

Reaction time is defined as the time interval between the appearance of a stimulus and the initiation of a response to it (Garg et al., 2013). It is usually expressed in milliseconds.

The ability to monitor, identify, process and respond quickly to an unpredictable environment is an important aspect of natural behavior. Healthy individuals are adept at generating appropriate and rapid responses in response to stimuli associated with potentially dangerous situations. These responses are called reactions and are characterized by the ability to generate extremely fast and spatially precise movement in the face of a situation. Examples include corrective reactions to maintain balance, protective reactions to driving or to a potentially harmful stimulus (Janssen, 2015).

Reaction time can be divided into three components (Akhani et al., 2015):

1. Perception time: the time required to perceive the stimulus;

2. Decision time: the time required to decide an appropriate response to the stimulus;

3. Motor time: the time to execute the motor command received in response to the stimulus.

There are three types of experiments based on reaction time (Luce, 1986):

1. Simple reaction time: requires a single response to a single stimulus (eg pressing a key on a computer when hearing a sound signal);

2. Recognition reaction time: requires a response only when certain stimuli appear (pressing a key on a computer only when the letter "x" appears on the screen, not when another letter appears;

3. Choice reaction time: the response must be appropriate to the stimulus (pressing the "space" key when the letter "x" appears on the screen and pressing the "enter" key when the letter "z" appears on the screen).

Reaction time can be divided into three categories according to the nature of the stimulus, visual, auditory or tactile. Reaction time is a valid indicator of the speed of processing of the sensory stimulus by the nervous system and its execution as a motor response (Akhani et al., 2015).

This cognitive-motor connection is a critical factor in many aspects of daily life including, but not limited to: quick decision making in dangerous situations, improved athletic ability, injury prevention, and sustained autonomy with aging.

Reaction time is influenced by a number of factors, such as:

- experience – affects the reaction time by anticipating the stimulus;
- stimulus intensity;
- number of stimuli (see choice reaction time);
- gender and age – studies show that men usually have a lower reaction time than women;
- consumption of alcohol, drugs or medicines;
- quality and duration of sleep;
- physical condition - a better physical condition is correlated with a lower reaction time;
- reaction time training – several studies have shown improvement in reaction time through various means.

3.2.2. Modalities to Reduce Reaction Time

There are different mechanisms to explain faster reaction time in those who exercise regularly. This may be due to improved concentration, alertness and better and improved muscle coordination in speed and accuracy mode. Physical activity leads to improved cognitive performance, particularly cognitive flexibility, a measure of executive function.

Throughout our lives, during the practice of a sport or even in our daily activities, we will encounter a multitude of situations where the ability to act quickly can be of great help. For example, when you're driving a car and another vehicle suddenly pulls out in front of you, a slow reaction time can mean the difference between safety and danger. This also applies to simple inattention, in the event of tripping or slipping. The brain must react quickly to visual and tactile stimuli. Also a low reaction time is important to prevent long-term vision damage from exposure to high intensity light (Roda, 2020).

There are various means to improve reaction time. Strengthening the connection between the body and the brain can make a noticeable difference in the ability to react to the environment.

Training a specific movement or action is one of the most used methods to improve reaction time. One of the best ways to decrease reaction time is to train your body to respond to stimuli as quickly as possible through exercise. Sprinters often work to improve reaction times by simulating the explosive starting sound of a gunshot or bell. Getting your body comfortable with that response can make all the difference when every second counts, like in athletics.

3.2.3. Modalities to Reduce Reaction Time through Virtual Reality

With the development of technology, new opportunities have arisen to reduce reaction time using state-of-the-art technology such as virtual reality. Active video games require visual-spatial skills, hand-eye or foot-eye coordination, and quick reaction time to successfully operate these games.

For exergames to influence physical development, designers have developed systems to track and respond to players' gross motor movements (Staiano & Calvert, 2011).

The improvement of reaction time by practicing exergames results from the improvement of the transmission of nerve impulses through neural pathways. When engaged in new experiences, the brain creates new neural circuits (Stroud & Whitbourne, 2015).

These circuits are like routes made up of interconnected neurons. These routes are created in the brain through daily use and practice; just like a trail on a mountain route made by daily use by tourists or professional climbers.

There is evidence of positive transfer from virtual training to real-world psychomotor improvements supporting the use of these virtual exercises (Hulteen et al., 2015; Gray, 2017; Barbosa et al., 2020).

The active video game Reakt directly targets complex reaction time, requiring the choice of the appropriate motor response depending on the presented stimulus (Neurotrainer, 2021).

One of the means used in our study is the active video game Eleven Table Tennis. Table tennis is characterized by perceptual uncertainty and time constraints. As a dynamic sport, it involves a constantly changing visual environment.

Studies have shown that table tennis players have faster reaction times than non-table tennis players (Akhani et al., 2015; Asar et al., 2022).

Another means used is the active video game The Thrill of Fight, which represents boxing in the virtual environment (Sealost Interactive LLC, 2019).

During a fight, subjects are constantly reacting to each other. Every dodge, punch and step taken by the opponent requires a quick reaction. For this reason, in order to fight, it is necessary for the participants to remain constantly focused on the opponent's movements and make quick decisions according to the circumstances (Polechoński & Langer, 2022).

Based on these, we included boxing in the virtual environment in the program for improving reaction time and hand-eye coordination.

3.3. Hand-Eye Coordination

An individual's ability to rhythmically and precisely execute a controlled movement is called coordination.

There are several types of coordination, including intersegmental coordination and eye-motor coordination. Eye-motor coordination requires the limbs to act according to visual stimuli. Eye-motor coordination can be: hand-eye or foot-eye (Reddy et al., 2017).

Hand-eye coordination can be defined as the ability to perform activities that require the simultaneous use of the eyes and hands (Mayer & Caminiti, 2018).

Hand-eye coordination in everyday life occurs in different contexts. Hand movements to a visual target may be made shortly after its presentation or delayed (Mayer et al., 2003).

Hand-eye coordination is at the heart of our daily actions and interactions with the objects and people around us and is central to understanding how the brain creates internal models of the action space and generates movement within it (Battaglia-Mayer & Caminiti, 2018).

When fixating on objects in our three-dimensional world, the eyes will usually target the objects of interest before any hand movement begins. Rapid eye movements called saccades are responsible for this fixation by shifting gaze from one part of the visual scene to another, bringing the object of interest into focus on the fovea, the portion of the retina with the greatest visual acuity (Jana et al., 2017).

Despite the wealth of psychophysical, neurophysiological and computational studies available on hand-eye coordination, little is still known about the synaptic mechanisms behind visuomotor integration that underlie and are relevant to the coordinated transformation of movements.

3.3.2. Modalities to Improve Hand-Eye Coordination

As with reaction time, muscle memory is often associated with improved hand-eye coordination.

When we learn a new skill or practice a particular movement, the brain creates neural pathways and connections that control the associated muscle groups (Davies & Rose, 2000).

These connections become more efficient and well-coordinated through repetition, performing the task with increased accuracy and ease. Muscle memory is a complex process involving both the muscular and nervous systems (HealthMax Physiotherapy Clinic, 2024).

Coordination is the basis of mastery of fundamental motor skills (Sheehan & Katz, 2013). Finding a method of teaching-learning coordination in a way that engages subjects in an interactive way is essential to the success of physical education programs (Patel & Bansal, 2018).

Improved coordination can translate into greater confidence and an increased likelihood of participating in physical activities (Trecroci et al., 2021).

Most of the activities carried out during the day use some degree of hand-eye coordination, which is why this coordination needs to be trained as much as possible.

In general, visual information is used to correct behavior that is not appropriate for a situation, and that is why this psychomotor ability is so important.

Training for hand-eye coordination uses psychomotor tasks aimed at both decreasing reaction time and increasing the subject's perceptual performance. This training requires subjects to detect a certain stimulus and react to it using their hands (Mughrabi et al., 2023).

Hand-eye coordination can be improved through activities that involve physical systems, for example, juggling the ball or throwing the ball against the wall. However, many trainers prefer digital systems as they can collect data on the subject's objective motor performance and provide direct feedback based on it (Făgăraș et al., 2023). This approach also allows the subject and the teacher to adjust the learning strategy more effectively (Mughrabi et al., 2023).

3.3.3. Modalities to Improve Hand-Eye Coordination through Virtual Reality

Virtual reality has brought new opportunities to improve hand-eye coordination using state-of-the-art technology.

Interactive electronic games can improve hand-eye coordination. An object control skill, such as grasping, involves tracking an object and then gaining control of it. The active video games Reakt and Eleven Table Tennis replicate these moves (For Fun Labs, 2020; Neurotrainer, 2021).

Recent advances in VR technology enable the use of HMDs to train hand-eye coordination.

The new generation of head-mounted devices has gained wide interest. These systems include display graphics enhancements. Perhaps more importantly, the current generation of head-mounted devices is notable for improvements in detecting user movement and using this information for real-time display (Munafo et al., 2017).

One of the methods used to improve hand-eye coordination is repetition, which is the basis of neuroplasticity changes in the brain. Each virtual game involves successive repetition of exercises in different planes of motion in each session (Costa et al., 2019).

When a new skill or task is learned for the first time, the brain begins to create new neural pathways. These pathways connect regions involved in motor planning and execution. The primary motor cortex is a key player in the initiation and control of voluntary movements. Learning involves strengthening the connections (synapses) between neurons. As movements are practiced, these synaptic connections become more efficient, allowing signals to travel faster and more safely along neural pathways (HealthMax Physiotherapy Clinic, 2024).

Video games involve a complex cognitive process of multitasking: paying attention to a computer screen or the virtual environment in the case of HMDs, receiving the visual or verbal informational stimulus, integrating the information with previous experience or prior knowledge in working memory, making a decision based on newly integrated knowledge, planning an action based on the decision, taking action and anticipating responses. All elements of this process can occur simultaneously in only a few seconds during an interactive game (Chen & Gao, 2014).

Active video games require visual-spatial skills, eye-hand or eye-foot coordination, and quick reaction time to successfully operate these games. For exergames to influence physical development, designers have developed systems to track and respond to players' gross motor movements (Staiano & Calvert, 2011).

Because many exergames such as Reakt or Eleven Table Tennis require fast eye-motor coordination, they can help improve general coordination skills.

Avoiding some objects (in red color) coming towards the participant and catching others (in yellow color) is a training program incorporated in the Reakt application aimed at hand-eye coordination.

This exergame provides continuous stimulation by constantly changing the speed of objects coming towards the participant as well as by continuously requiring the correct motor decision to be made according to the stimulus (Neurotrainer, 2021).

Part II Research on Improving Reaction Time and Hand-Eye Coordination of 17-19 Year Old Students through Virtual Reality

Chapter 4. Study 1 Systematic Literature Review on the Use of Virtual Reality for the Development of Psychomotor Skills

Introduction

The application of virtual reality for the purpose of developing psychomotor skills has recently been studied more and more by researchers.

However, mixed results have been provided for the effectiveness of training programs in the virtual environment. To address these issues, we conducted this systematic review of experimental studies published in the literature testing the effectiveness of virtual training programs on psychomotor skills.

According to Jensen & Konradsen (2018) the new virtual reality technology seems suitable for successful educational approaches and theories such as constructivism, active learning or simulation-based learning.

Although most studies published in the literature focus on rehabilitation, there are also published studies examining the effects of VR technology on the clinically healthy population (Lee et al., 2019; Levac et al., 2019; Michalski et al., 2019).

A literature review can provide clarity, identify gaps and trends regarding the topic under study, and provide insights that future research can address (Muun et al., 2018).

Therefore, the aim of this paper was to conduct a systematic literature review on interventions to develop psychomotor skills through virtual reality.

Methods

Search strategy

Studies that were included in the systematic review were searched in August 2022 on the following literature platforms: PubMed, ScienceDirect, Google Scholar.

The publication date we have chosen for these studies is the range 2015-2022. To search for these studies, we used combinations of the following terms: "virtual reality", "head mounted display", "motor skills", "psychomotor skills", "reaction time", "hand-eye coordination".

Inclusion and exclusion criteria

The criteria according to which the studies were included are the following:

- included studies must be experimental or quasi-experimental;
- studies published in English;
- each study must include a healthy population;

The criteria by which the studies were excluded are the following:

- studies that do not refer to the development of motor or psychomotor skills;
- studies that refer to rehabilitation.

Results

After searching the specialized platforms mentioned above and using the keywords and their combinations, 451 studies were found (Figure 3).

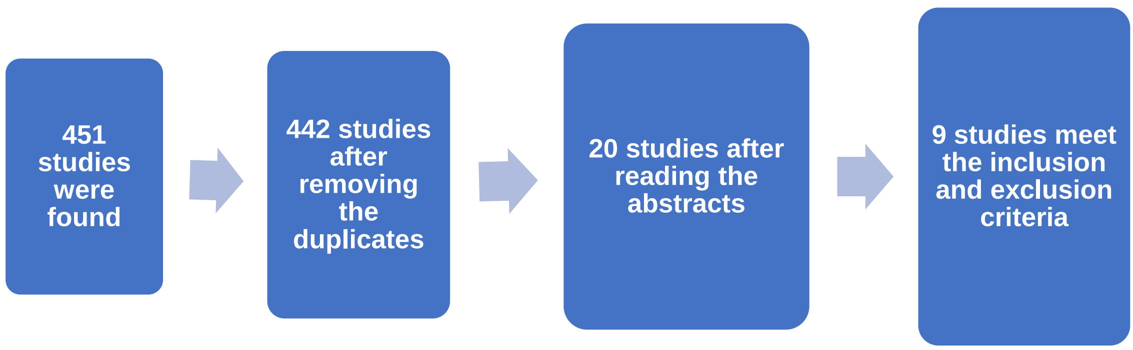

Figure 3. Selection of the studies

Study characteristics

Eleven studies out of twenty were excluded because they did not meet inclusion and exclusion criteria such as: did not develop motor or psychomotor skills, did not use a healthy population. From the nine studies, there is a combined total of 552 participants. The studies were published between 2015 and 2021. In the nine studies included in this review, sample sizes ranged from 10 to 261 participants. The age of the participants included in the studies was between 6 and 24 years. The duration of the VR intervention was between one day session and 9 months.

The shortest intervention lasted only one session (Drew et al., 2020) tested whether participants who train dart throwing skills in a virtual environment will improve their real world dart throwing skills. The longest intervention lasted nine months and tested the potential improvement in motor competence after a VR program (Sunyue Ye et al., 2018).

Six studies used VR HMDs and that made the VR interventions more immersive, three studies used less immersive VR devices.

Discussions

This paper aimed to review recent articles published in the field of using virtual reality to improve motor or psychomotor skills.

Gray used 80 male baseball players in his study and divided them into four groups: VE (virtual environment), VE+extra sessions, additional RBT (real baseball training) sessions, and normal training group. The duration of the study was 6 weeks, 2 sessions/week, 45 minutes each. Players in the VE group showed significant improvements in 7/8 tests (Gray, 2017).

In contrast to Gray (2017) study, a study by Drew et al. (2020) found no evidence of improvements in subjects following his darts program. This study examined how skills acquired in virtual reality compare to skills acquired in the real world, using training to complete a dart throwing task in a virtual or real environment.

A perceptual-motor approach was used in this study, using measures of task performance (accuracy) as well as perception (visual symptoms and oculomotor behavior) and motor behaviors (throwing kinematics and coordination).

Another study by Rutkowski et al. (2021) demonstrate the utility of a virtual reality intervention program on decreasing musicians' reaction time. The virtual reality training program by Rutkowski et al. (2021) improved hand-eye coordination and reaction time in musicians, which may lead to better mastery of musical instruments.

The study by Amprasi et al. (2021) suggest methods to improve reaction time, providing a useful tool for physical education teachers and coaches to improve reaction time in a different way. The purpose of this study was to investigate the effects of two educational interventions, a program based on a fully immersive virtual gaming environment and a traditional training program, on the whole-body reaction time of children aged 8-10 years. The study showed that whether it was a fully immersive virtual environment or traditional training, reaction time improved compared to a control group that received no training program (Amprasi et al., 2021).

In Barbosa et al. (2020) the intervention program resulted in improved heart rate relative to rest, also the intervention reduced SRT (simple reaction time).

Studies such as the one by Petri et al (2019) in particular, which used successful international kumite karate athletes, all with black belts to build an avatar that was used in the intervention program, demonstrated the usefulness of VR training even and for performance athletes whose skills are already at a level of excellence.

Petri et al (2019) find that athletes' decreased reaction times are a suitable method to analyze changes in perception and anticipation due to VR training. These new findings can be used in karate training to improve motor learning in beginners to improve performance.

Conclusions and future research

Whether the participants were students (Vernadakis et al., 2015; Sunyue Ye et al., 2018; Barbosa et al., 2020; Tharani et al., 2020; Rutkowski et al., 2021) or athletes (Gray, 2017; Petri et al., 2019; Amprasi et al., 2021) these studies demonstrated that a virtual reality training program can improve motor and psychomotor skills.

Participants in the virtual environment interventions improved their motor performance in 8 of the 9 selected studies. The only study in this review that did not show an improvement in motor or psychomotor skills was Drew et al. (2020), a fact perhaps caused by the short duration of the training program, being the shortest intervention, lasting only one session.

The small number of studies included in this review suggests that there is a great need for research investigating the ability of VR technology to improve motor or psychomotor skills.

Chapter 5. Study 2. Pilot study

5.1. Aim

Research being a long and complex process, mistakes and problems are expected to occur during the research. This is where the pilot study comes in to micro-simulate the research tracking possible errors and problems, as well as exploring planning efficiency and examining alternatives. Also, familiarization with testing methods and means is achieved, thus eliminating possible problems but also forming a series of hypotheses that will be examined in the research stages.

The purpose of the study is to investigate the exercise program in the virtual environment in a relatively short period of time - 12 weeks, to track the effects on the hand-eye coordination and reaction time in high school students.

5.2. Hypothesis

Following the review of the specialized literature described in the previous chapter, we believe that the duration of the intervention program of 12 weeks is sufficient to produce the proposed psychomotor changes.

Thus we propose the following hypotheses:

1. Through a program of specific exercises (exergames) carried out in immersive virtual reality, for 12 weeks we will be able to reduce the complex reaction time of 17-19 year old students.

2. Through a program of specific exercises (exergames) carried out in immersive virtual reality, for 12 weeks we will be able to improve the hand-eye coordination of 17-19 year old students.

5.4. Stages of Conducting the Pilot Study

Stage I (October 2022 – December 2022)

1. Studying specialized literature to form opinions regarding the intervention program;
2. Establishing the inclusion and exclusion criteria of the subjects;
3. Identification of scientifically validated and widely used tests in scientific research that we can apply in preliminary research;
4. Establishing the intervention program after studying the specialized literature regarding the indications and contraindications of the training program in the virtual environment.

Stage II (January 2023)

1. Formation of groups for the pilot study;
2. Initial assessment of subjects included in the pilot study.

Stage III (January 2023 – April 2023)

1. Carrying the intervention program 2 times a week.

Stage IV (April 2023 – May 2023)

1. Final evaluation of the subjects included in the pilot study;
2. Interpretation of the data obtained from the pilot study.

5.5. Methods

All statistical tests were performed using the Statistical Package for the Social Sciences (SPSS) version 29 for Windows (IBM SPSS, Chicago, IL, USA). The significance level for all statistical tests was set at $p < 0.05$.

The Shapiro-Wilk test was used to decide whether the data were normally distributed within the two groups.

Descriptive statistics and t-test were performed to compare subject characteristics between both groups. The independent t-test was performed to compare the mean values of the measured variables between both groups. The t-test for paired groups was performed to compare the pre- and post-intervention mean values of the variables measured in each group.

5.6. Inclusion and Exclusion Criteria

- High school students aged between 17 and 19;
- Clinically healthy, with no evidence of diseases or conditions that may interfere with the intervention program;
- Not be enrolled in any sports club or other form of organized exercise practice.

5.7. Evaluation Methods

All tests used in both the pilot study and the experimental study are scientifically validated and approved.

- Alternate-Hand Wall-Toss Test

It is a test of hand-eye coordination, in which the participant throws a ball against a wall with one hand and tries to catch it with the opposite hand.

Purpose: checking the hand-eye coordination ability in speed mode.

Resources needed: Tennis ball, timer, smooth wall.

Procedure: A sign is placed 2 meters from the wall. The subject stands behind the line and facing the wall. The ball is thrown with one hand towards the wall and must be caught with the opposite hand when returning from the wall. The ball is then thrown back towards the wall and caught with the original hand. The test continues for 30 seconds (Mackenzie, 2009).

- Deary-Liewald Reaction Time Test

It was designed by Ian Deary and programmed by David Liewald. For complex reaction time, four white squares are positioned in a horizontal line in the middle of the computer screen, set against a blue background. Four keys on a standard computer keyboard correspond to different squares. The position of the keys corresponds aligned with the position of the squares on the screen: the "z" key corresponds to the far left square, the "x" key to the second square from the left, the "comma" key to the second square from the right, and the "period" key to the farthest square right. The stimulus is represented by the appearance of a cross within one of the squares. A cross appears randomly in one of the squares and participants must respond as quickly as possible by pressing the appropriate key on the keyboard. The inter-stimulus interval varies between 1 and 3 s and is randomized within these limits (Deary et al., 2011).

5.8. The Intervention Program

A total of 16 Romanian students, aged between 17 and 19, were recruited from a high school in Cluj-Napoca. The participants were informed about the risks of participating in the research, we also received the written consent of the students, respectively of the parents or legal representatives for minor students.

To determine the effect of the intervention program, the participants were divided into two groups, one experimental (n=8) and the other control (n=8). Subjects in the experimental group participated in the intervention program based on virtual reality, subjects in the control group only participated in the physical education classes in the school curriculum.

Since it is a pilot study where we test the reliability of the research methods and means to be applied in the fundamental study, the intervention program lasted 12 weeks, 2 times a week, with 40 minutes each session (of which 5 -7 minutes represents the preparation of the body for the effort, 30 minutes the fundamental part and 1-3 minutes the recovery of the body after the effort).

Each session began with a standard warm-up, variations of exercises to prepare the body for effort, selective influencing of the locomotor apparatus, used in the lesson of physical education and sports, and ended with the recovery of the body after the effort.

In the intervention program we used the Oculus Quest 2 (Facebook Technologies, LLC. 1 Hacker Way, Menlo Park, CA 94025, SUA).

To evaluate complex reaction time, we used the Deary-Liewald reaction time test (Deary et al., 2011), and to evaluate hand-eye coordination, we used the Alternate-Hand Wall-Toss Test (Mackenzie, 2009). The tests were described in the previous subsection.

The subjects were tested before and after the application of the intervention program. The tests were done in the same time frame, and the testing manner was similar, so that there were no errors in the experiments.

The means used were the active video games (exergames) Reakt, OHShape, Eleven Table Tennis and The Thrill of the Fight.

5.10. Discussions

This study was conducted to determine the effect of the virtual reality intervention program through exergames on reducing reaction time and improving hand-eye coordination in high school students. 16 students who met the inclusion-exclusion criteria were selected from a high school in Cluj-Napoca. The age of the students was between 17 and 19 years. They were randomly selected into two groups, both equal in number. Group 1 (experimental group) to which we applied the VR intervention program includes 4 male and 4 female students. Group 2 (control group) which includes 4 male and 4 female students who only participated in physical education classes in the school curriculum.

You et al. (2005) showed that contact with the virtual environment provided by VR has the ability to increase activation in the primary motor cortex. Also according to HealthMax Physiotherapy Clinic (2024) learning involves strengthening the connections (synapses) between neurons.

As movements are practiced, these synaptic connections become more efficient, allowing signals to travel faster and more safely along neural pathways.

Rutkowski et al. (2021) propose in their study that ambidextrous training through music games in immersive reality can cause an increase in cortical functionality for symmetrical areas involved in motor, auditory and visuospatial processing, as well as in the white matter of the corpus callosum, similar to tool training ambidextrous musical instruments such as the piano.

Devranche et al. (2005) examined the effect of an experimental manipulation on complex reaction times, dividing it into premotor and motor time, and the possibility of determining whether the effects of the manipulation on reaction time occur after or before the onset of electromyographic activity, and therefore whether affect the execution of the response.

The results of the study show that the complex reaction time was faster in the exercise condition (262 ms) than in the rest condition (275 ms). The authors point out that physical exercise affects motor time, but exerts little influence on premotor time (Davranche et al., 2005).

The Exergames phenomenon is one of the innovative and fun ways to motivate children and adolescents to be active and develop their motor skills (Staiano et al., 2013).

Several studies have indicated that the integration of exergaming into physical education classes contributes to increasing children's energy expenditure, both in the short and long term, possibly due to the fun component (Sunyue Ye et al., 2018).

Stroud & Whitbourne (2015) conducted three experiments in which they tested the attentional components of two groups of adults, young and older, playing three different games. The findings suggest that regular practice of video games improved reaction time.

5.11.Conclusions

After conducting the pilot research, we managed to reach the following conclusions:

The exercise program in the virtual environment proved to be a pleasant but also demanding activity for the students.

Subjects in the experimental group showed statistically significant ($p < .05$) improvements between initial testing ($M = 24.75$, $SD = 3.012$) and final testing ($M = 28.13$, $SD = 2.696$); $t = -5.974$, $p = <.001$ in the hand-eye coordination test.

Subjects in the experimental group showed statistically significant ($p < .05$) improvements between initial testing ($M = 412.38$, $SD = 35.238$) and final testing ($M = 381.00$, $SD = 34.822$); $t = 7.961$, $p = <.001$ on reaction time test.

Subjects in the experimental group showed better values at the final test compared to the control group in the hand-eye coordination test: the experimental group ($M = 28.13$, $SD = 2.696$) and the control group ($M = 24.88$, $SD = 2.900$); $t = 2.322$, $p = 0.018$.

Subjects in the experimental group showed better values at the final test than the control group in the reaction time test: the experimental group ($M = 381.00$, $SD = 34.822$) and the control group ($M = 412.38$, $SD = 33,419$); $t = -1.839$, $p = 0.044$.

The exercise program in the virtual environment was properly structured, dosed and planned to be able to achieve benefits on the targeted skills.

Virtual reality through specific means - exergames or active video games, as they are also called, can be used as physical exercises and can represent a means to improve reaction time and hand-eye coordination.

The conclusions confirm the research hypothesis according to which the exercise program in the virtual environment can improve hand-eye coordination and reaction time of high school students.

The preliminary research provides the premises for expanding the research on a larger number of subjects and over a longer period of time to be able to formulate final conclusions regarding the effects of exercises in the virtual environment on the hand-eye coordination and reaction time of the subjects.

Chapter 6. Study 3. Fundamental Research

6.1. Aim

Through our work, we aimed to investigate the effects of an intervention program based on immersive virtual reality to improve hand-eye coordination and reaction time in 17-19 year old students, as well as the effects on their involvement in sports activities.

6.2. Hypothesis

The results obtained on the 16 subjects included in the preliminary research represent a scientific argument that allows us to expand the research on a larger group of subjects over a longer period of time.

After thorough documentation by studying the most relevant studies in this field of virtual reality, we came to the conclusion that the duration of 6 months is suitable to obtain relevant results following the intervention program.

Thus, the hypotheses of the experimental research are:

1. Through a program of specific exercises (exergames) carried out in immersive virtual reality, for 6 months we will be able to reduce the simple and complex reaction time of 17-19 year old students.

2. Through a program of specific exercises (exergames) carried out in immersive virtual reality, for 6 months we will be able to improve the hand-eye coordination of 17-19 year old students.

3. Forming beliefs about the role of physical exercise to improve the quality of life.

6.5. Stages of Conducting the Experimental Research

Stage I (September 2023 – March 2024)

- Preparation of samples and initial testing (Sep 2023);
- Application of the intervention protocol (October 2023 – March 2024);

Stage II (March - April 2024)

- Final evaluation of subjects (March 2024);
- Processing and interpretation of the obtained data (April 2024);
- Formulation of conclusions (April 2024).

6.6. Methods

The research methods used were the same as in the pilot study (they are described in the previous chapter).

6.7. Inclusion and Exclusion Criteria

• High school students aged between 17 and 19;

• Clinically healthy, with no evidence of diseases or conditions that may interfere with the intervention program;

• Not be enrolled in any sports club or other form of organized exercise practice.

6.8. Evaluation Methods

- **Alternate-Hand Wall-Toss Test**

The Alternate-Hand Wall-Toss test is a test to evaluate hand-eye coordination. This test was described in the previous chapter.

- **Deary-Liewald Reaction Time Test**

It was designed by Ian Deary and programmed by David Liewald. It is a simple and complex reaction time test. For simple reaction time, a white square is positioned roughly in the center of a computer screen on a blue background. The stimulus is represented by the appearance of a square cross. Each time a cross appears, participants must respond by pressing a key as quickly as possible.

The inter-stimulus interval (the time interval between each response and when the next cross appeared) varies between 1 and 3 s and is randomized within these limits (Deary et al., 2011).

The complex reaction time variant of this test was described in the previous chapter.

- **Ruler Drop**

This test uses the known properties of gravity to determine how long it takes a person to respond to a falling object by measuring how far the object can fall before being caught (Mackenzie, 2004).

Purpose: To test reaction time for the dominant and non-dominant hand

Equipment needed: Ruler.

Procedure: the subject to be tested stands or sits near the edge of a table, resting his elbow on the table so that his wrist extends to the side. The examiner holds the ruler vertically in the air between the participant's thumb and forefinger, but without touch. The zero mark on the ruler will line up with the participant's fingers. The participant must indicate when they are ready. Then, without warning, the evaluator releases the ruler and lets it fall—the subject must catch it as quickly as possible as soon as he sees it fall.

Record the distance in centimeters at the level the participant grasps the ruler. This procedure will be repeated 3 times and the average score that will be recorded will be calculated.

- **Plate Tapping Test**

The Plate Tapping test is a reaction test that uses an alternating tapping action on a horizontal surface (Eurofit, 1993).

Purpose: it is used to measure upper limb reaction and hand-eye coordination.

Equipment needed: table, yellow discs with a diameter of 20 cm, rectangle (30 x 20 cm), timer.

Procedure: the two yellow discs are placed with their centers 60 cm apart on the table. The rectangle is placed equidistant between both discs. The non-dominant hand is placed on the rectangle. The subject moves the hand between the discs over the middle hand as quickly as possible. This action is repeated for 25 complete cycles (50 touches).

The time required to complete 25 cycles is recorded. The test is performed twice and the best result is recorded.

- **The Godin-Shephard questionnaire for the assessment of physical activity**

The questionnaire allows the evaluation of self-reported physical activity during free time.

The leisure time physical activity score is expressed in units and can be calculated in two steps. First, the weekly frequencies of vigorous, moderate, and light activities are multiplied by nine, five, and three, respectively; these last three values correspond to the categories of MET values of the listed activities.

The total weekly leisure activity score is calculated in arbitrary units by summing the products of the separate components, as shown in the following formula: (Godin, 2011).

Weekly leisure activity score = (9 × Vigorous) + (5 × Moderate) + (3 × Light).

6.9. The Intervention Program

A total of 32 Romanian students, aged between 17 and 19, were recruited from a high school in Cluj-Napoca. The participants were informed about the risks of participating in the research, we also received the written consent of the students, respectively of the parents or legal representatives for minor students.

To determine the effect of the intervention program, the participants were divided into two groups, one experimental (n=16) and the other control (n=16). Subjects in the experimental group participated in the intervention program based on virtual reality, subjects in the control group only participated in the physical education classes in the school curriculum.

The actual research was carried out in the high school gym, the intervention program lasted 6 months, 2 times a week, with 40 minutes each session (of which 5-7 minutes represent the preparation of the body for effort, 30 minutes the fundamental part and 1-3 minutes recovery of the body after the effort). Each session began with a standard warm-up, variations of exercises to prepare the body for effort, selective influencing of the locomotor apparatus, used in the lesson of physical education and sports, and ended with the recovery of the body after the effort.

In the intervention program we used the Oculus Quest 2 (Facebook Technologies, LLC. 1 Hacker Way, Menlo Park, CA 94025, USA).

For the evaluation of hand-eye coordination we used the Alternate-Hand Wall-Toss and Plate Tapping tests. To evaluate simple and complex reaction time we used the Deary-Liewald reaction time test, and the Ruler Drop test was used to evaluate the reaction time of the dominant and non-dominant hands. The tests were described in the previous subsection.

The Godin-Shephard questionnaire (Godin, 2011) was used to assess physical activity.

The subjects were tested before and after the application of the intervention program. The testing was done in the same time frame, and the testing manner was similar, so that there were no errors in the experiments.

The means used were the active video games (exergames) Reakt, Thrill of Fight, OHShape and Eleven Table Tennis (these were described in detail in the previous chapter).

6.11. Discussions

This study was conducted to determine the effect of the virtual reality intervention program through exergames on reducing simple and complex reaction time and improving hand-eye coordination in high school students.

32 students who met the inclusion-exclusion criteria were selected from a high school in Cluj-Napoca. The age of the students was between 17 and 19 years. They were randomly selected into two groups, both equal in number. Group 1 (experimental group) to which we applied the VR intervention program includes 6 male and 10 female students. Group 2 (control group) which includes 6 male and 10 female students who only participated in physical education classes in the school curriculum.

The result of the current study showed that there were statistically significant reductions ($p < .05$) in simple and complex reaction time and improvement in hand-eye coordination between pre- and post-test in the experimental group. There was also a significant difference (p <

.05) in post-test scores between the experimental and control groups on all tests except the Ruler Drop test for the non dominant hand.

Although the literature has mainly focused on the use of exergames to improve or maintain health (Anderson Hanley et al., 2012; Buettner et al., 2020) and rehabilitation (Taylor & Griffin, 2015) and most studies have investigated the effects of exergames on the elderly (Anderson Hanley et al., 2012) or people with disabilities (Lee et al., 2019) we also managed to identify studies that are consistent with our study and that aim to improve psychomotor skills or increase involvement in motor activities of age students school or high school as in the case of our study (Dos Santos et al., 2016; Sunyue Ye et al., 2018; Rutkowski et al., 2021).

Our results are in accordance with the results of Shin et al. (2015), who showed an improvement in hand–eye coordination in children with cerebral palsy using the Nintendo Wii. As in our study, training took place twice a week with a similar time, 45 minutes each session but the total duration was much shorter, 8 weeks (Shin et al., 2015).

Politopoulos et al. (2015) presented a case study in which an active video game called Tennis Attack was used to exercise and improve the reaction time of tennis players. After evaluating the game, the researchers analyzed the reaction times of the players to see if there was any significant change. The results were positive as there was an improvement in the reaction times of the players. Players between the first and fifth rounds had statistically significant changes in their times (<0.05) (Politopoulos N. et al., 2015).

Another study aimed to improve reaction time through exergames conducted by Ziagkas et al. (2018) reported an improvement in reaction time after the intervention program. The experimental group showed mean reaction time ($M = 0.844$ s, $sd = 0.092$) and the control group ($M = 1.045$ s, $sd = \pm 0.205$). The experimental group showed a significant improvement ($p = 0.000$).

Amprasi et al. (2021) conducted a study to define the effect of two educational interventions, an immersive virtual reality program and a traditional program, on improving reaction time in children aged 8-10 years. Similar to our study, researchers confirmed the hypothesis that participants who practiced in immersive virtual reality improved their reaction time (Amprasi et al., 2021).

Tharani et al. (2020) conducted a study consistent with our study and regarding the age of the selected sample, the study was conducted on 10 participants aged between 18-24 years with the aim of discovering the effect of games practiced in virtual reality on stress, anxiety and reaction time after 4 weeks of intervention. Analysis of results indicated a significant difference between initial and final testing for all variables ($p<0.05$).

The results of the pilot study Dos Santos et al. (2016) are more promising than what they anticipated and confirmed in the original theory that active video games can help motivate children who are usually sedentary to be more active. The 24-month follow-up survey after the end of the intervention program showed promising results regarding the exergaming intervention. Of the original 55 participants, 30 responded to a telephone follow-up. Almost all (96.7%) reported that they would participate in a similar program again. In any case, perhaps the most significant finding was that 23 out of 24 children who had never participated in any sport or organized physical activity started participating after the program. Swimming and soccer were among the most popular activities reported (Dos Santos et al., 2016).

Our study also focused on improving hand-eye coordination.

Hand-eye coordination is closely related to reaction time, so its training is important to improve reaction time (Politopoulos & Tsiatsos, 2022).

Hickman et al. (2017) conducted a study to examine the current evidence on the use of active video games to improve motor function in children with movement disorders, including cerebral palsy, developmental coordination disorder, and Down syndrome. All articles presented in their study showed an improvement in outcomes through active video games, although differences were not significant in all articles compared to conventional therapy (Hickman et al., 2017).

Longitudinal evidence in European children indicated the benefits of better motor coordination for healthy body weight and increased physical activity providing protection against physical activity decline over time (Page et al., 2017).

Hulteen et al. (2015) conducted research to investigate whether training motor skills with active video games can transfer these skills to the real world. The results demonstrated that some motor skills can be trained through exergames.

Chapter 7. Conclusions

After conducting the experimental research, we managed to reach the following conclusions:

The exercise program in the virtual environment proved to be a pleasant but also demanding activity for the students, evidenced by the fact that none of the participants abandoned the study, even if it had a relatively long duration, namely 6 months.

Subjects in the experimental group showed statistically significant improvements ($p < 0.05$) between initial and final testing in tests of hand-eye coordination, both in the Alternate Hand-Wall-Toss test: initial testing ($M = 20.56$, $SD = 3.66$) and final testing ($M = 24.31$, $SD = 4.36$); $t = -7.20$, $p = <0.001$; as well as in the Plate Tapping test: initial testing ($M = 12.18$, $SD = 1.06$) and final testing ($M = 11.04$, $SD = 0.95$); $t = 9.26$, $p = <0.001$.

Subjects in the experimental group showed statistically significant improvements ($p < 0.05$) between initial and final testing on reaction time tests, both on the Deary-Liewald test for simple reaction time: initial testing ($M = 268.25$, $SD = 18.69$) and final testing ($M = 253.81$, $SD = 14.03$); $t = 7.16$, $p = <0.001$; as well as the Deary-Liewald test for complex reaction time: initial testing ($M = 402.06$, $SD = 26.31$) and final testing ($M = 382.75$, $SD = 21.30$); $t = 7.60$, $p = <0.001$.

Subjects in the experimental group showed statistically significant improvements ($p < 0.05$) between initial and final testing on the Ruler Drop reaction time tests for the dominant hand: initial testing ($M = 16.61$, $SD = 3.21$) and final testing ($M = 14.91$, $SD = 3.07$); $t = 7.22$, $p = <0.001$ and non dominant hand: initial testing ($M = 17.48$, $SD = 2.85$) and final testing ($M = 16.72$, $SD = 2.38$); $t = 3.53$, $p = 0.002$.

Subjects in the experimental group showed statistically significant improvements ($p < 0.05$) at the final test compared to the control group in both tests for hand-eye coordination, Alternate Hand-Wall-Toss: experimental group ($M = 24.31$, $SD = 4.32$) and the control group ($M = 21.50$, $SD = 3.32$); $t = 2.05$, $p = 0.02$; Plate Tapping: experimental group ($M = 11.04$, $SD = 0.95$) and control group ($M = 11.76$, $SD = 1.08$); $t = -2.00$, $p = 0.02$.

Subjects in the experimental group showed statistically significant improvements ($p < 0.05$) at the final test compared to the control group in simple and complex reaction time tests, simple Deary-Liewald: experimental group ($M = 253.81$, $SD = 14.03$) and group control ($M = 266.25$, $SD = 20.08$); $t = -2.03$, $p = 0.02$; Deary-Liewald complex: experimental group ($M = 382.75$, $SD = 21.30$) and control group ($M = 396.88$, $SD = 25.37$); $t = -1.70$, $p = 0.04$.

Subjects in the experimental group showed statistically significant improvements ($p < 0.05$) at the final test compared to the control group in the Ruler drop reaction time test for the dominant hand only, in the test for the non dominant hand the differences were not statistically significant (p >. 05) Ruler drop (dominant hand): experimental group (M = 14.91, SD = 3.07) and control group (M = 16.84, SD = 3.28); t = -1.71, p = 0.04; Ruler drop (non dominant hand): experimental group (M = 16.72, SD = 2.38) and control group (M = 17.88, SD = 2.87); t = -1.24, p = 0.11.

Subjects in the experimental group showed statistically significant improvements ($p < 0.05$) in 2 of the 3 variables of the Godin-Shepard questionnaire for the assessment of physical activity at the final test compared to the control group. They also showed statistically significant improvements ($p < 0.05$) in all 3 variables of the questionnaire between initial and final testing.

Subjects in the control group did not show statistically significant improvements (p >.05) on any of the tests.

The exercise program in the virtual environment was properly structured, dosed and planned in order to achieve improvements in the targeted skills.

Following the analysis of the results obtained in the motor tests and in the questionnaire between the initial and final testing, but also between the experimental and the control group, we can state that all three hypotheses formulated by us have been confirmed, as follows:

- The program of specific exercises (exergames) carried out in immersive virtual reality, for 6 months, reduced the simple and complex reaction time of 17-19 year old students;
- The program of specific exercises (exergames) carried out in immersive virtual reality, for 6 months, brought improvements on the hand-eye coordination of 17-19 year old students;
- Following the analysis of the data of the Godin-Shepard physical activity questionnaire, we also confirm the hypothesis that the students will form some beliefs about the role of physical exercise to improve the quality of life.

Virtual reality through specific means - exergames or active video games, as they are also called, can be used as physical exercises and can represent a means to improve reaction time and hand-eye coordination, as well as increase the level of involvement in motor activities of students.

7.1. Impact of the Study and Original Contributions

Regarding the theoretical impact, we note that we have not identified any studies in the literature that used a long-term structured intervention program in immersive virtual reality in clinically healthy high school students to improve their reaction time and hand-eye coordination, and this was an opportunity for us to test the efficiency of this means.

At the level of practical impact, following our research we can state that all three hypotheses were confirmed and this means could be used by high school students to decrease reaction time and improve hand-eye coordination, which represent two of the more important psychomotor skills for the current or future involvement of students in the various forms of organized physical exercise practice.

However, the study has some limitations. One of them is the rather small number of subjects. Another limitation is that the participants, even if they stated that they did not participate in organized motor activities during their free time, participated in physical education classes in the school curriculum in addition to our intervention program, which could have contributed to some measure to the improvements seen in our study.

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