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Application of local vibration to stimulate cognitive functions in adolescents

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Abbreviations

PA	Physical Activity
LIPA	Low Intensity Physical Activity
MVPA	Moderate to Vigorous Physical Activity
MET	Metabolic Equivalent
BMBWF	Bundesministerium für Bildung, Wissenschaft und Forschung (Federal Ministry for Education, Science and Research)
BMSGPK	Bundesministerium für Soziales, Gesundheit, Pflege und Konsumentenschutz (Federal Ministry for Social Affairs, Health, Care and Consumer Protection)
HBSC	Health Behavior in School-aged Children
AACAP	American Academy of Child and Adolescent Psychiatry
WBV	Whole Body Vibration
VEE	Vibration Exercise Equipment
BAfEP	Bundesbildungsanstalt für Elementarpädagogik (Federal educational institute for elementary education
PTO	Number of Processed Target Objects
OE	Omission Errors
CE	Confusion Errors
CP	Concentration Performance
E%	Error percentage
CG	Control Group
EG	Exercise Group
VEG	Vibration Exercise Group
COWAT	Controlled Oral Word Association Test
PAMPA	Prospective Study About Mental and Physical Health
PE	Physical Exercise
TRV	Tonic Vibration Reflex
WBV	Whole Body Vibration
IFRW	Immediate Free Recall Words
DSRN	Delayed Serial Recall Numbers
AT	Acoustic Test
ST	Sensitivity Test
LSD	Least Significance Difference

1. Introduction

1.1. Physical activity and sedentary behavior

The new *World Health Organization 2020 Guidelines on Physical Activity and Sedentary Behavior* report that according to recent global estimates more than three-quarters (81%) of adolescents do not meet the recommendations of at least 60 minutes of physical activity (PA) presented in the *2010 Global Recommendations on Physical Activity for Health* (Bull et al. 2020). These new guidelines, which are an update of the WHO's recommendations of 2010, not only show the amount (frequency, intensity, duration) and type of recommended physical activity with significant health benefits for different population groups such as children and adolescents (5–17 years), adults (18–64 years), older adults (65 years and older), pregnant and postpartum women and people living with chronic conditions but also the health impact of sedentary behavior. In children and adolescents there are adverse health effects of a higher amount of sedentary time concerning fitness and cardiometabolic health, adiposity, social behavior and sleep duration. There is a strong recommendation of reducing the sedentary time, especially the recreational screen time (Bull et al. 2020).

The sedentary time of children increases when they start with primary school (Carson, 2016). During working days, the proportion of sitting time in school in relation to the total sitting time is 57% (Huber et al. 2017). The current teaching and learning style is predominated by motionless teaching methods except explicitly promoted movement projects such as moving breaks or animated learning (e.g. Fessler et al. 2008, Kottmann et al. 2008; Bös, 2004) and the regular sports and exercise classes which vary from 1 to 4 hours per week depending on the school type and level. Only schools with the main emphasis on sports and movement propose between 5 and 8 hours of physical education per week (BMBWF, 2021). In recent years the number of hours spent on physical education has been reduced in the timetables of Austrian and German schools (Neumann, 2012; Julie 2018)

In the reports of physical activity of school-aged children and adolescents in Austria, Germany and Switzerland there is a clear tendency to less MVPA the older the children/adolescents are. In Switzerland for example 99,8% of the 6 and 7 years old children reach the WHO recommendations of 60 minutes of MVPA daily while only 21,5% of the 14–16 years old meet this goal.

The time of daily MVPA decreases from about 144 minutes of 6 year old children to about 40 minutes of 16 year-old adolescents (Fig.1). In Austria and Germany the situation is comparable (BMSGPK, 2018; Finger et al. 2018; Gesundheitsförderung Schweiz, 2016).

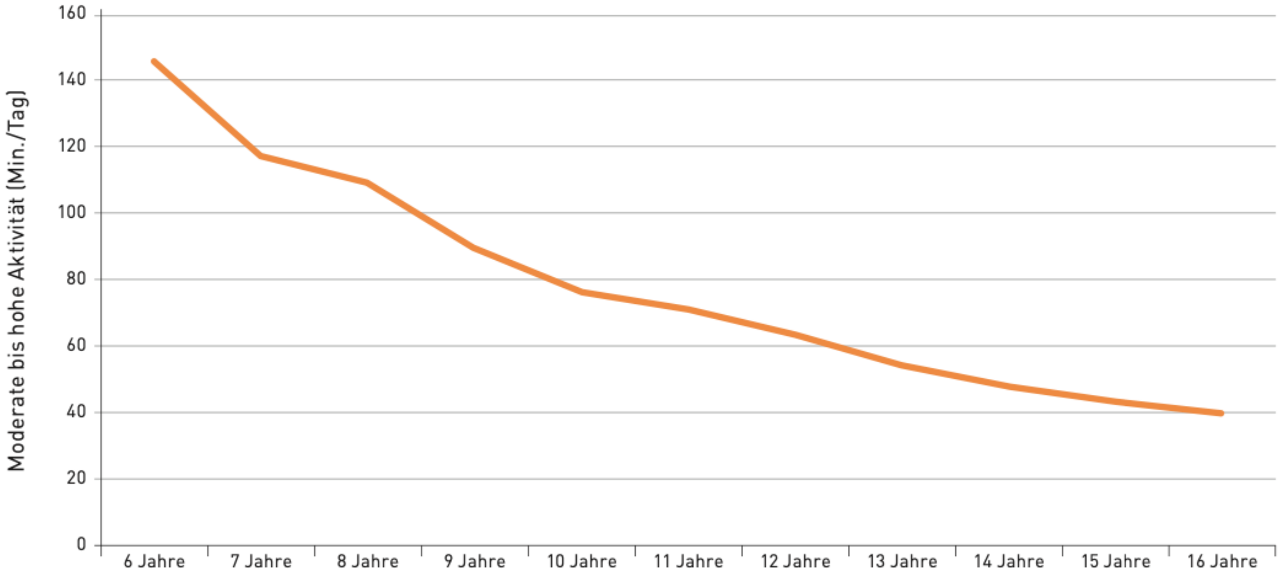

Figure 1: Average minutes spent at moderate to high intensity per day by age (n=1320),

(SOPHYA Studie Swiss, TPH 2016; https://gesundheitsfoerderung.ch, 23/07/2022, 10:38)

In addition to the lack of physical activity in schools and educational institutions school-aged children and adolescents spend between 2 and more than 6 hours a day in front of the screens of the new media (computer, smartphone, tablet) and continue the low-mobility lifestyle in their free time (Der Spiegel, 2012).

New studies reveal that the screen time of children and teenagers has remarkably increased the last years. On average children between 8 and 12 years spend between 4 and 6 hours per day using screens and adolescents spend up to 9 hours in front of TV, computer, tablet, smartphone and gaming console screens (The Common Sense Census, 2019; AACAP, 2020).

The Analysis of Sedentary Times of Children and Adolescents between 4 and 20 Years (Huber and Köppel, 2017) where the sedentary behavior of more than 4000 children and adolescents in Austria, Germany and Luxembourg has been examined, shows the average sitting time on work and week-end days: 10,58h on work days which correspond to 71% of the waking time and 7,52h on weekend days which correspond to 54% of the waking time (Huber et al. 2017).

The sedentary lifestyle in adolescent years continues in adults life as a study among Australian adults shows: more than half of the waking hours is spent in sedentary activities, the rest of the time in light intensity physical activity (LIPA) such as standing with some ambulation and only 4–5% of the time is accorded to moderate to vigorous physical activity (MVPA). This represents 9,3h of sedentary time, 6,5 h of LIPA and only 0,7h of MVPA (Owen et al. 2009)

The new *World Health Organization 2020 Guidelines on Physical Activity and Sedentary Behavior* not only underlines the importance of promoting physical activity (PA) but also of reducing sedentary behaviors across all age, groups and abilities (Bull et al. 2020)

For the present work, the findings for the group of 5–17 year old are of particular interest. Studies reveal that regular PA in childhood and adolescence may lead to physically active adults (e.g. Daley, 2002; Livingstone et al. 2003; Parry, 2015). So it seems important to establish positive exercise habits in young people to keep them in adult age and to benefit from the positive health effects.

With an average of 60 minutes of moderate-to-vigorous physical activity (MVPA) daily many of the benefits such as improved physical, mental and cognitive health outcomes are observed, activity beyond this recommended daily time even provides additional health benefits. In contrast greater time spent in sedentary behavior is associated with negative health outcomes, especially for television viewing or recreational screen time. There was not enough evidence to set a threshold of sedentary or recreational screen time (Bull et al. 2020)

Sedentary behavior or activities are characterized by low energy expenditure. For the description of body mass neutral energy expenditure of activities the metabolic equivalent (MET) is used. The resting metabolic rate is defined by 1 MET, running has a value of at least 8 METS, moderate walking is in the range of 3–4 METS and sedentary activities are from 1 to 1,5 METS (Owen et al. 2009).

Many studies show a positive correlation between exercise and physical health (e.g. Biddle et al. 2004; Tittlbach et al. 2011; Nething, 2006) and also positive effects on cognitive abilities and emotional well-being or mental health (e.g. Biddle et al. 2011; Donnelly et al. 2016; Esteban-Cornejo et al. 2015; Etnier et al. 1997; Marti et al. 1999; Nething et al. 2006).

Numerous publications dealing with brain-level learning highlight the importance of exercise for learning, concentration, memory, cognitive functions and academic achievement (e.g. Castelli et al. 2007; Ericsson, 2008; Hillman, 2005; Hillman, 2008;

Taras, 2005; Sibley et al. 2003, Zurek 2012, Sarna 2020). In addition, there have been promising projects related to "moving learning" for several years that examine the various aspects of physical activity in schools and make interesting classifications, such as in the project StuBSS (study on the development of movement, play and sport in the all-day school of the University of Marburg, Germany). There is a distinction between learning and development-accompanying and learner-closing functions, and practical suggestions for the implementation of the respective priorities of daily movement units are listed (Kuritz et al. 2016).

1.1.1. PA and cognitive functions

The influence of PA on cognitive functions has been investigated intensively the last years and positive effects on the brain and cognitive functions have been established. Several number of studies showed that PA and aerobic exercise in moderate or vigorous intensity can improve cognitive functions and academic achievement (Hillman et al. 2008; Álvarez-Bueno et al. 2017; Donelly et al. 2016). Most of the improvements reached through PA have been associated with cognitive functions situated in the prefrontal cortex such as attention and other executive functions (Chang et al. 2012). Results of studies showed differences in acute and long-term effects of PA. Long-term associated changes due regular PA were noted in neurochemical and neuroanatomical systems and the data suggest that PA prevents the brain from detrimental diseases and effects of aging. PA and long-term exercises improve neurogenesis and neuroplasticity, the production of BDNF and may contribute to prevent, delay or treat neurodegenerative processes and cognitive decline (Basso and Suzuki, 2017). Concerning the influence of acute PA (a single session of exercise) on cognition there is only weak evidence and small overall positive effects on cognition related to the prefrontal cortex were found (Sibley and Etnier, 2003). Different effects of acute PA according to the intensity of the exercises on speed and accuracy of cognitive performance were documented (McMorris and Hale, 2012). The outcome of another meta-analysis was similar: the effect of acute PA on cognitive functions was positive and small. Therefore, it seems to be important to do more research on parameters such as exercise duration, intensity and the type of assessed cognitive performance (Chang et al. 2012). Nevertheless, acute PA of approximately one hour has shown benefits on cognitive processes such as attention, memory, problem solving, language, cognitive flexibility, and inhibitory control (Basso et al. 2015; Basso and Suzuki, 2017).

Acute PA of maximal intensity may have negative effects on cognitive performance and impair brain function immediately after exercising and for special cognitive tasks which demand complex processes like the working memory, verbal tasks and attention (Esteban-Cornejo et al. 2015; Samuel et al. 2017).

Future studies for understanding the relation of PA and cognitive functions are needed. Differences between regular long-term exercises and short-term effects of acute exercises, the duration of the training intervention, the kind of training, group or individual activity, the intensity of the exercise intervention and the age of the investigated population seems to be important factors to be considered in future investigations. Also, the kind of cognitive ability which is designed to be influenced by PA has to be outlined and examined clearly with appropriate tests. The range of cognitive functions is very extensive (memory, inhibitory control, language, perception, attention, concentration, accuracy, processing speed etc.) and has to be determined in order to get clear assignments and more information of the effects of PA on specific cognitive functions.

1.1.2. Covid 19 and health related behavior

The measures of the Covid 19 pandemic have reinforced the development to more use of screens, more sedentary time and less physical activity in youth even more (Schmidt et al. 2020). An investigation of Spanish children and adolescents during Covid 19 confinement summarizes the main effects on health-related behaviors as the following: reduced physical activity level, increased screen exposure and sleep time and reduced fruit and vegetable consumption (Lopez-Bueno et al. 2020). Another review of studies reported that children and adolescents from 0–19 years had lower physical activity and mental health associated problems during the first wave of the Covid 19 pandemic due to school closures and general lockdowns (Viner et al. 2022). The importance of the impact of the Covid 19 pandemic and the governmental distancing measures and lockdowns on health behaviors of children and adolescents is shown in a review investigating the changes of PA and sports before and during the Covid 19 pandemic. According to this review the decrease in PA of children and adolescents ranged between -10,8 and -91 min per day. Singular increases were detected in relation to unstructured and outdoor activities. The practice of sports and PA is related to determinants such as age, gender, socioeconomic status and the outdoor environment (Rossi et al. 2021).

Due to the decrease of PA, the fitness level and significant physical determinants such as the BMI changed. In a study conducted in England during the first year of Covid 19 (data collected from October 2019 to November 2020 among children from 8 to 10) a significant increase of the BMI and overweight/obesity from 33% to 45% was stated. The increase of the BMI was associated with a lower physical well-being. The risk of future diseases related to the lack of PA and overweight/obesity such as cardiovascular and metabolic diseases are a big concern. Measures to promote sports and PA programs are necessary to improve as well physical fitness and mental health (Basterfield et al. 2022).

The Covid 19 pandemic and its measures not only had drastic consequences on PA of young people, but also a negative impact on mental and psychological health of children and adolescents. According to COPSY, a representative German study on mental health and quality of life during the pandemic, 71% of children and adolescents between 7 and 17 years report a lower health-related quality of life. The mental health problems including anxiety and depressive symptoms almost doubled and their health behavior worsened (Revens-Sieberer et al. 2021).

An obvious association between PA and the mental health during the first year of the Covid 19 pandemic has been noted in a worldwide review among people of all ages. According to the findings of the review children and adolescents had to face important changes in the education system by learning online which probably contributed to a higher anxiety level concerning the academic development. Nevertheless, active groups reported less depression and anxiety symptoms, better sleep and better mood states. The number of days per week of PA was revealed to have a bigger impact on mental health than the minutes of PA per day. More vigorous activity showed better results on improvement of the mental health status (Marconcin et al. 2022).

Children and adolescents have been exposed to special conditions during lockdowns and school closures. Interruptions in education, online teaching and learning, social distancing, sustained uncertainty etc. elicited states of anxiety and fear. Especially in adolescents changes in cognitive functions and performance have been observed as a consequence of a higher level of stress and anxiety and lower mental health and well-being. The constant worry about the future was reported being the main factor for anxiety in young people. An association between anxiety and cognitive difficulties such as attention, planning and memory has been found. Difficulties with mood resulted in reduced ability to plan and prioritize and lower focus and concentration (Attwood et al. 2022).

A German study investigated age-related cognitive effects of the Covid 19 restrictions. Increased psychological distress can lead to increased anxiety which negatively affects cognitive functions. Social isolation was identified being negative for cognitive performance across all ages and different cognitive tasks as well as affectedness and loneliness especially in young and middle-aged people. This could be a consequence of lower cognitive stimulation during periods of home-office, social distancing and isolation. A difference between subjective cognitive performance and objective performance was noted: while the subjective cognitive performance decreased over time objective cognitive performance increased slightly which speaks for a general training effect. The subjective cognitive performance is highly associated with depressiveness and loneliness (Menze et al. 2022).

The association of PA on cognitive performance, especially memory has been examined in the PAMPA (Prospective Study About Mental and Physical Health) cohort study. The findings show, that PA during social distancing reduced the likelihood of subjective memory decline and cognitive impairment in adults. The study highlights the potential of PA to reduce the consequences of Covid 19 pandemic on cognitive function and mental health (Feter et al. 2021).

Already before Covid 19 pandemic and its restrictions and consequences on peoples' physical and mental health, the links between PA and health related well--being concerning physical, mental, social and cognitive aspects were well examined and programs for all ages to promote PA proposed. Especially for adolescents who didn't meet the general recommendations of the WHO guidelines of 60 minutes of moderate PA per day already before the pandemic, the situation during and after the Covid 19 pandemic period got even worse (Attwood et al. 2022). These findings underline the importance of maintaining PA during the Covid 19 pandemic and especially after this period of time. A survey of more than 2000 children grades 3 to 12, which corresponds to the ages of 8 to18 years conducted in the US shows the decrease of PA and PE (physical exercise) during the Covid 19 pandemic (Fig. 2) and underlines the importance of continued PA through different ways: school programs, supervision and support from parents and community-based leadership support. According to the findings of this study, activity needs and physical education has to be prioritized in the planning of the districts (Pavlovic et al. 2021).

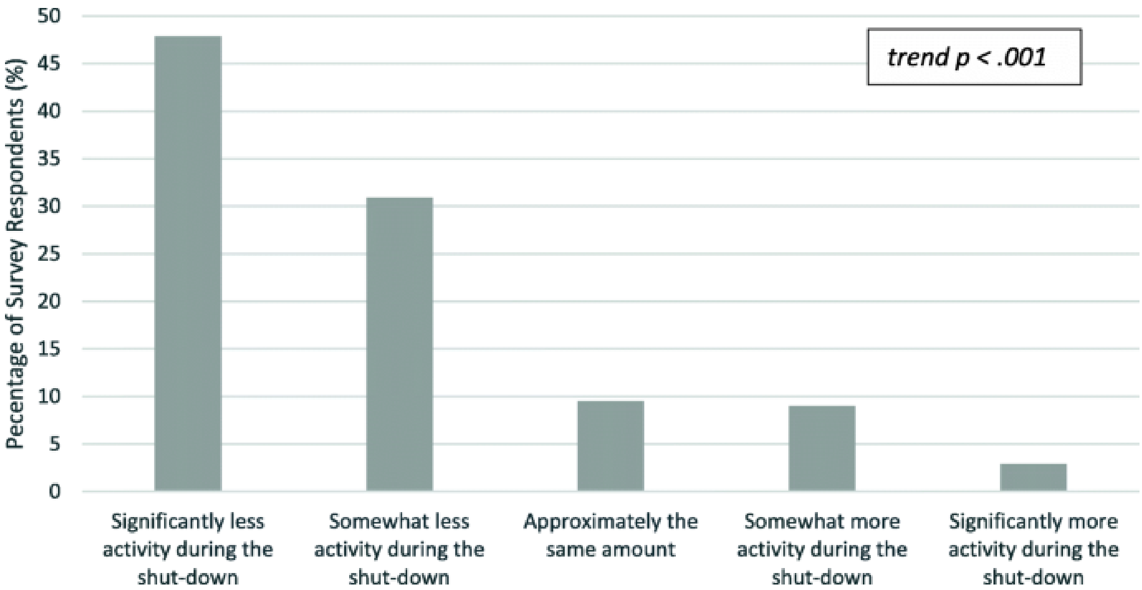

Figure 2: Illustration of amount of PA during the first wave of Covid 19 in US during school closures compared to the amount obtained in typical school setting

(Pavlovic et al. 2021, DOI: 10.1186/s12889-021-10545-x; Retrieved 06/08/2022, 9:33)

Especially after the Covid 19 pandemic the promotion and integration of sports programs and PA in the life of children and adolescents is of major priority. There is big evidence of the positive influence of PA on cognitive development (Mandolesi et al. 2018; Aguirre-Loaiza et al. 2019; Doherty et al. 2019) and embodied cognition offers promising perspectives in the improvement of cognitive processes through movement. The interconnections of body movement, PA, action and perception patters with cognitive skills (e.g. control, anticipation, perception, discrimination, memory) seems to be important for the future learning methods for school-aged children and students. The storage of knowledge through motor actions and the integration of the environment with the human body is more and more considered as an important factor of learning. Regarding these findings body activities should be integrated in all subjects in school by educational policies (Aguirre-Loaiza et al. 2021)

Considering the worldwide tendency of decrease in PA and the increase in sedentary behaviour among young people (WHO HBSC, 2020) even more during Covid 19 pandemic (Schmidt et al. 2020; López-Bueno et al. 2020) and the associated impact in physical, mental and psychological health there is an important need to improve the offer of PA and reduce sedentary time. It is even necessary to use or develop highly effective exercise programs with significant health effects to balance the lack of physical activity among all age groups but especially in children and adolescents with particular regard to the stimulation of cognitive functions.

1.2. Mechanical vibration

1.2.1. Basics of mechanical vibration

A mechanical vibration is a periodic oscillatory motion around an equilibrium point of an elastic system. In a physical system an external force is needed to generate an internal reaction which leads to propagate the movement by a vibrational wave. Two main categories of vibration exist: free and forced. Free vibrations are created by an external force like an impulse and get to their initial equilibrium point of minimum potential energy without restraint and creating smaller and smaller displacements. Forced vibrations are continuously generated by an external source such as mechanical vibrators or acoustic wave generators.

The parameters necessary to describe vibration are the time (t), frequency (f) and amplitude (A). The frequency is the number of oscillatory movements (waves) during a period of time, it is measured in Hertz (number of waves per second). The higher the number of waves the higher the frequency and the higher the sound.

The amplitude refers to the maximal deflection of the oscillation and determines the intensity of the mechanical vibration or the volume of a sound.

A phenomenon of elastic systems is the resonance frequency which means the natural frequency where a physical system oscillates with the highest amplitude. If the external force applied on the medium acts with a frequency near or equal to the resonance frequency of the object, energy is stored and the movement and the amplitude becomes larger and the duration of the oscillation longer (Corsetti and Casciani, 2017).

1.2.2. Mechanical vibration and human perception

Mechanical vibrations are defined as being oscillations which can be felt or/and heard by humans whereby the transition from the sense of touch to the auditory sense may be fluent.

The sense of touch is a complex system of neuronal structures which provides information about the environment by contact with the skin through pressure, stretch and vibration (Bear et al. 2009) by different types of subcutaneous mechanoreceptors (Fig. 3) all innervated by myelinated type II Aβ nerve fibres (Saggini and Ancona, 2017).

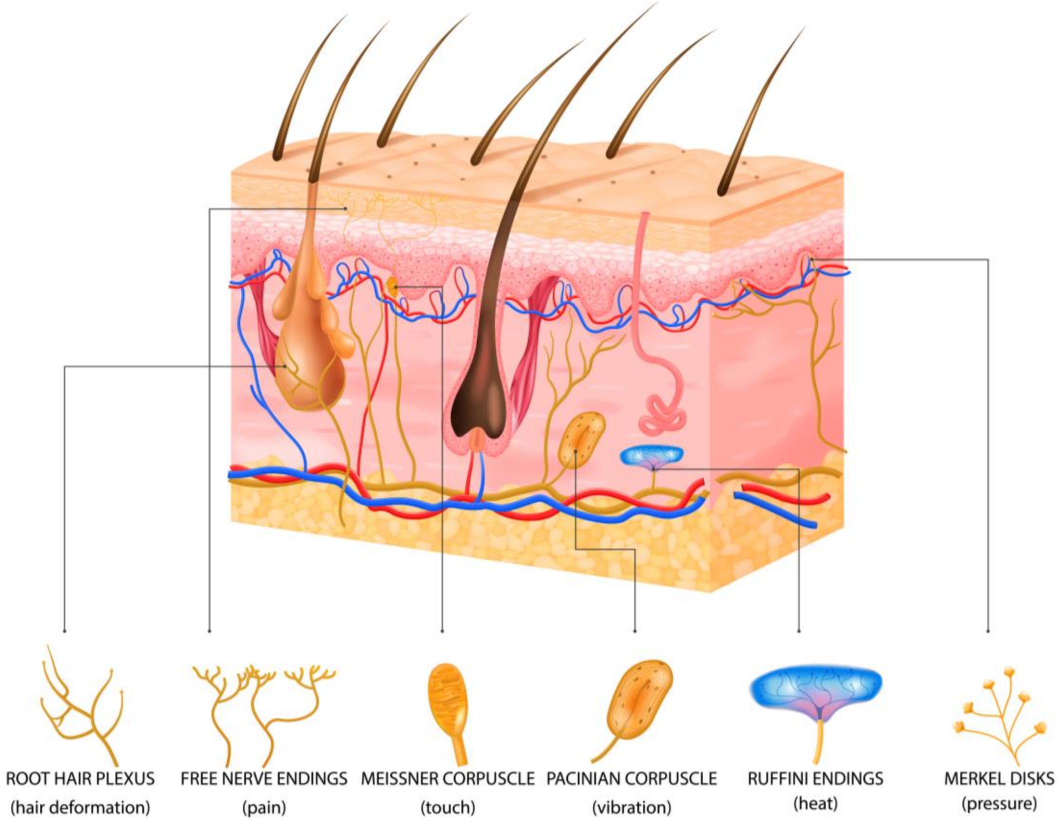

Figure 3: Skin sensory receptors

(https://www.freepik.com/free-vector/skin-sensory-receptors-concept-with-nerve-and-hair-flat_16220839.htm; Retrieved 04/09/2022, 13:01)

According to their frequency vibration stimuli are either identified by Meissner's corpuscles in the epidermis (best sensitivity of lower frequencies around and lower than 50 Hz) and Pacinian corpuscles in the dermis (best sensitivity of higher frequencies around 200–300 Hz) (Bear et al. 2009). Both receptors are type II which means that they have a wide and not exactly determined receptive field where the sensitivity fades out gradually. This comes out even more for the Pacinian corpuscles in reason to their position in deeper layers of the skin (Saggini and Ancona, 2017). Mechanoreceptors are not distributed homogenous under the skin surface and the density of afferent receptor units may be higher in certain places (e.g. fingertips, lips) than in others (e.g. back, legs) which is understood by spatial discrimination and has to be considered by using various stimuli on different parts of the body (Bear et al. 2017).

Both, Meisser's and Pacinian corpuscles, are rapidly adapting receptors which means that they are responding rapidly on vibration by firing at the beginning of the contact with the stimulus and interrupting the impulses despite persistent equal vibrational signal (Bear et al. 2017).

Vibration stimuli are not only detected by Meissner's and Pacinian corpuscles but also by mechanoreceptors in the muscles which are called muscle spindles. They are part of the proprioceptive system and provide information about muscle length and stretching. Vibration directly applied on the muscle leads to the tonic vibration reflex (TVR) which has been discovered in 1966 by Eklund and Hagbarth. This means a sustained contraction of the stimulated muscles by a reflexive response starting from the muscle spindles and activating the alpha motoneurons. The antagonist shows the adverse reaction, namely relaxation of the muscle (Saggini and Ancona, 2017).

Above mentioned receptors are stimulated by vibration and fire when the threshold is reached, which means that the neural signal is transmitted through the nerve pathways to the spinal cord or brainstem. The transmission velocity of these impulses, so called action potentials, is between 35 and 75 m/s in primary afferent Aβ II fibers, which are myelinated and transmit vibration stimuli. Action potentials are created by reaching the threshold of about -50mV when the resting potential of a neuron (-70 mv) is disturbed by a stimulus and crosses the nerve pathways in the form of an electrical signal. This signal reaches the primary somatosensory cortex of the Gyrus postcentralis, situated in the parietal lobe of the brain (Fig. 4) where the complex processing of information takes place (Baer et al. 2017).

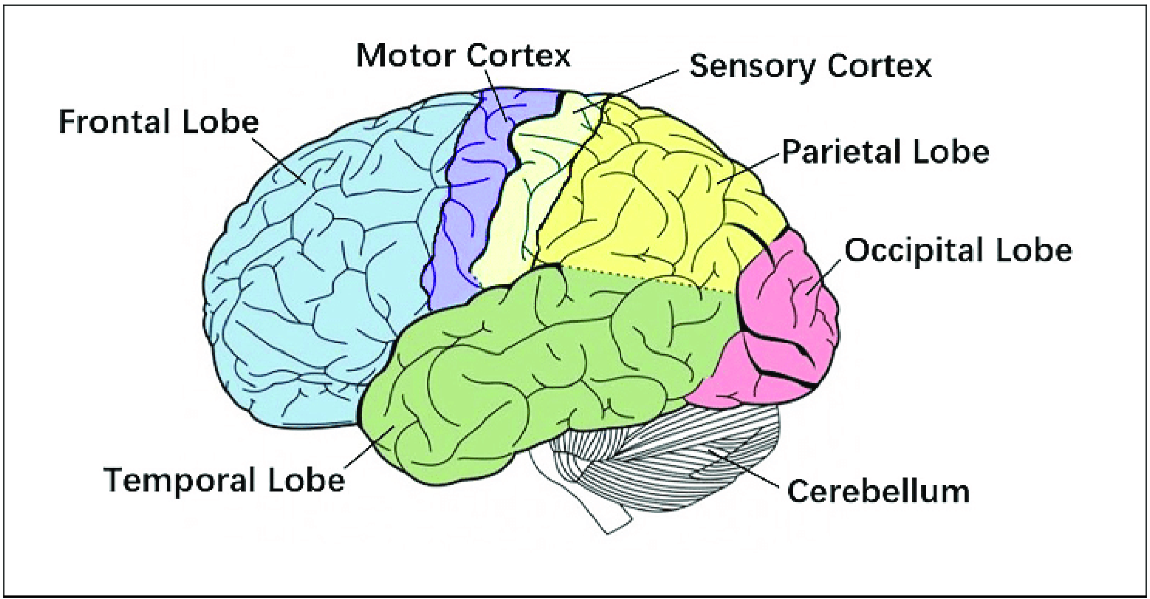

Figure 4: Primary brain regions

https://www.researchgate.net/figure/Primary-brain-regions-Motor-cortex-is-the-region-in-charge-of-planning-control-and_fig2_331905251

1.2.3. Types of vibration

Mechanical vibration used so far in therapeutic or healing activities are usually applied in two ways, either as whole-body vibration or as local vibration (Fig. 5). This categorization refers to the application of vibration either on the entire body or on individual parts of the body.

Whole Body Vibration (WBV)

The entire human body is exposed to the vibration by standing, lying or sitting on a vibrating object (Griffin, 1994).

Local/regional/focal Vibration

The transmission of the vibration to the human body takes place only by defined regions, for example by the hands or feet. Only a part of the body is directly exposed to the vibration (Griffin, 1994).

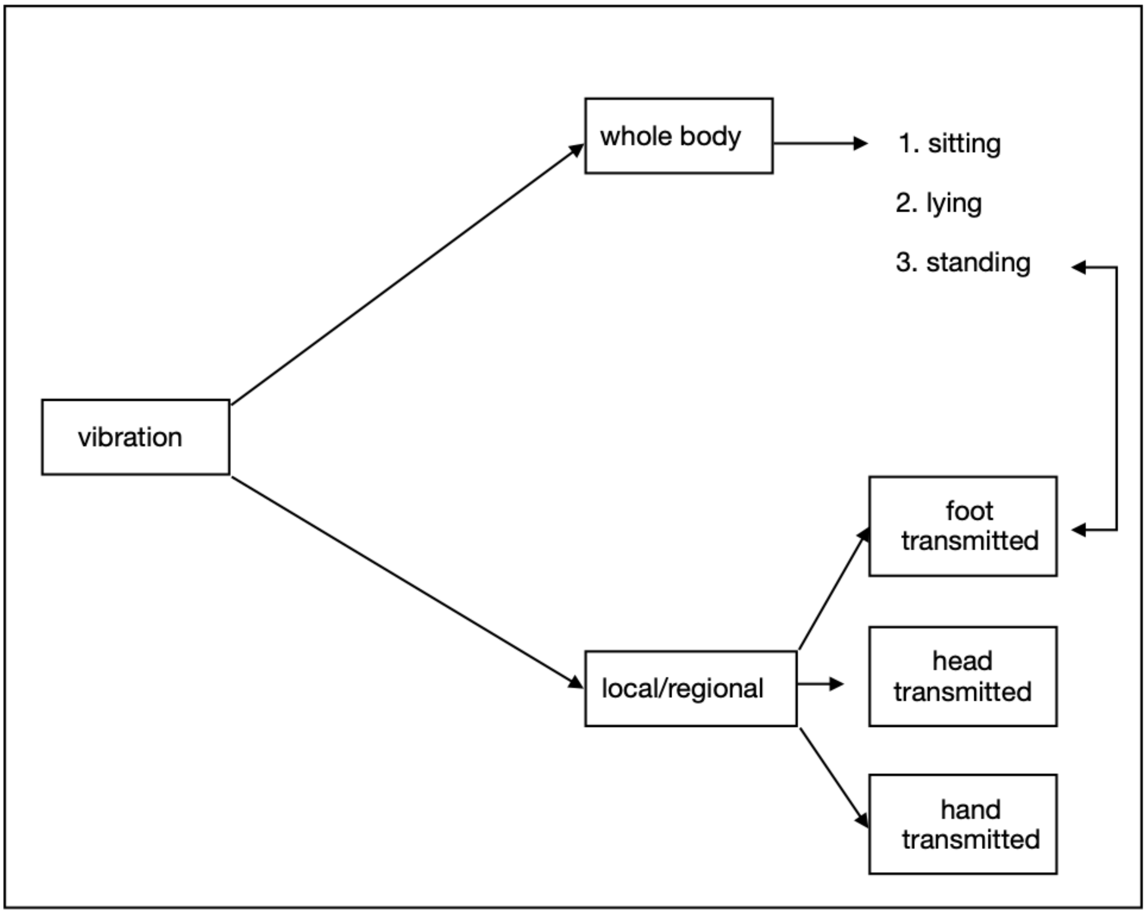

Figure 5: Whole body vibration and local/regional vibration on the human body (according to the model of Griffin, 1994)

1.2.4. Effects of vibration

Depending on the parameters (amplitude, frequency) and the type of vibration as well as the kind of exposure of humans to vibration (duration, intensity, parts of the body, etc.), vibration can have negative or positive effects on the human organism.

Negative effects of vibration

Exposure to vibration with a high intensity and for a long duration can lead to severe health problems. Especially on working places there are important hazards and strict controls concerning the contact of working men with vibration. Common health problems due to harmful vibration are hand-arm syndrome, white finger syndrome, headache, back pain, stomach problems, sleep disturbances, visual problems, etc. (Issever et al. 2003).

Positive effects of vibration

Controlled vibration with a determined range of frequency and intensity which is used in training and therapy may have positive effects according to the applied parameters (Müller, 2008) and turns out be an effective kind of training in regard to musculoskeletal structures (Cardinale and Wakeling, 2005; Zurek et al. 2022). The effects of WBV have been examined in numerous studies and reports (e.g. Cardinale and Pope, 2003; Cerciello et al. 2016; Luo et al. 2005; Marín and Rhea, 2010). On the one side there are promising results of the application of vibration in sport concerning maximal force, muscle strength and power, flexibility and recovery through massage by vibration equipment although some parameters of the effects of vibration training still have to be investigated more intensively (e.g. Issurin, 2005; Jordan et al. 2005; Wilcock et al. 2009) and on the other side vibration is more and more used in therapy especially in the neurological and musculoskeletal field. The main domains of its effectivity is reported in affecting the density of bone mass, sarcopenia, postural control, gait, stability, balance, pain control, the endocrine system, the neuromuscular and sensorimotor system (de Zepetnek et al. 2009; Wu et al. 2020; Loreto et al. 2004; Saggini et al. 2017). Vibration training has been intensively examined for neurological conditions in the last years and depending on the training parameters like frequency, amplitude, acceleration, duration etc. it seems to be beneficial in diseases such as Parkinson's disease, Multiple sclerosis, ALS etc. (e.g. Sharififar et al. 2014; Kaut et al. 2016; Kantele et al. 2015; Haas et al. 2006).

1.2.5. Determined versus stochastic frequency of vibration

Most vibration generating devices such as vibrating platforms, vibrating dumbbells or vibrating balls are motor driven and create vibrations with determined frequencies in the range of approximately 20–70 Hz. The frequency can be adjusted according to the application and does not change from itself during the training (Vasconcellos et al. 2014). In contrast there are devices creating vibration with stochastic frequencies which are characterized by constantly changing and rapidly alternating frequencies so that they can neither be determined nor predicted or calculated. Several studies investigated the use of stochastic resonance especially in people with neurological disorder such as Parkinson's disease, Amyotrophic lateral sclerosis, Multiple sclerosis etc. and found that the effects of stochastic resonance vibration was similar to the natural stochastic behavior of nerve cells what led to a significantly higher neuromuscular activation than with harmonic sinus stimulation (Haas et al. 2007). It was shown that if harmonic sinus waves not reaching the threshold for creating action potentials were superimposed by so called „noise“ (stochastic signals) the stimulus triggered a high number of action potentials (Fig. 6).

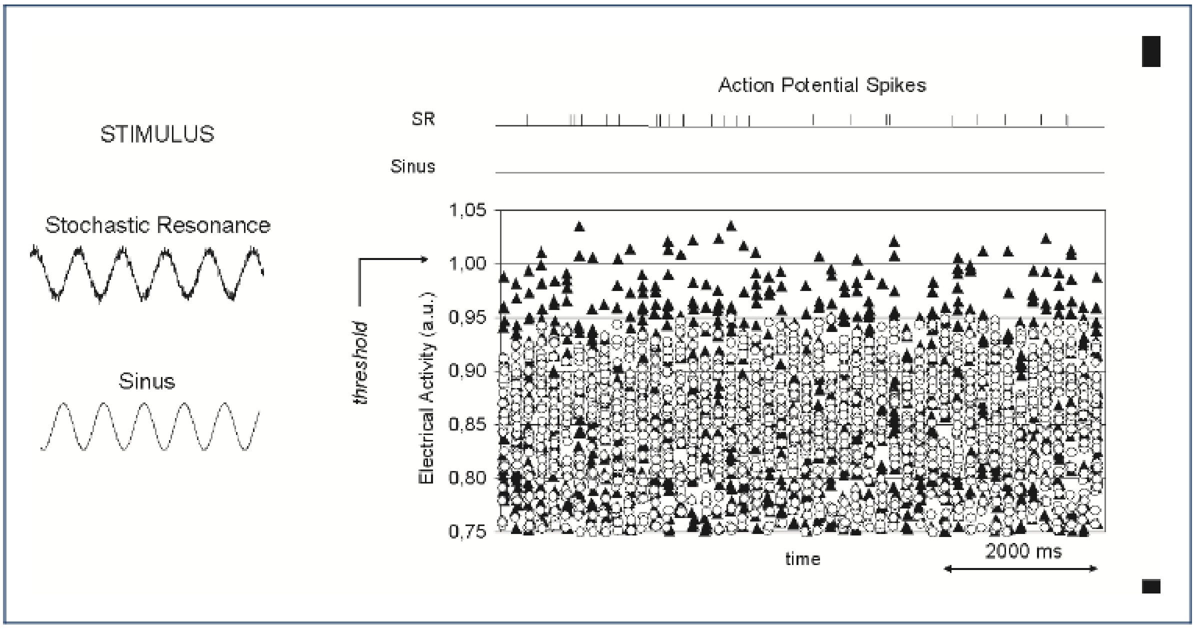

Figure 6: Comparison of action potentials through sinus waves and stochastic resonance (Haas et al. 2005)

Adding stochastic signals to a periodic oscillation improves the processing of the stimuli via the afferent neural pathways and leads to better neuromuscular responses and motor control (Haas et al. 2005). Improvement of balance, gait, postural control and the release of neurotrophic factors have been noted in patients with neurological disorders by using stochastic resonance therapy (Haas et al. 2007).

The frequency spectrum of the vibration generating device (VGD) used in this study reaches from 0 to about 460 Hz and was measured by a sensor fixed at the soft grip of the handle. It shows a mean amplitude at about 60 Hertz. The VGD is a handheld swing-ring system and provides local vibration transmitted by the hands to rest of the body. The vibration is not motor driven but depends on the natural and swinging movements of the rings at different levels and directions, therefore it does not achieve a constant frequency but a constantly and rapidly changing stochastic oscillating signal. Vibration measurements through a sound analyzer show permanently changing frequency while swinging the VGD (Fig. 7).

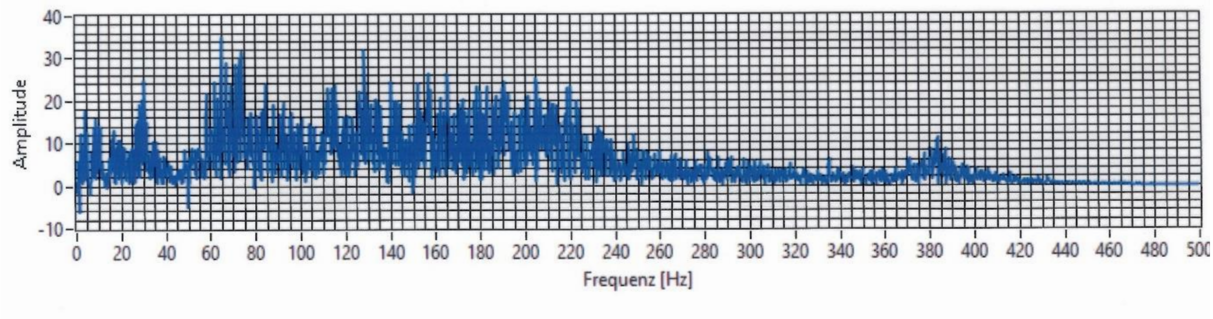

Figure 7: Frequency spectrum of one swinging movement with the VGD
(smovey GmbH, 2022, with kind permission)

Regarding the characteristics of the oscillation and frequency of the VGD and the sound created by swinging it which is not regular but a „noise“ in the physical definition of chaotic acoustic waves, it is a device generating stochastic vibration.

At the moment there is only little knowledge about PA and specific exercises combined with the VGD. A recent study investigated the VGD in middle-age and older women with chronic low back pain and only weak findings about the effectiveness of the VGD on decreasing pain and muscle activity of the erector spine and increasing lumbar range of motion occurred (Zurek et al. 2022).

One further study and one pilot intervention have been conducted using the VGD in patients with breast cancer (Crevenna et al. 2015; Cenik et al. 2020) and assessed the quality of life, upper limb muscle strength and body composition after the training intervention period. In both studies improvements in all parameters have been found.

No investigations about the use of VGD in children, adolescents or young people have been conducted yet. Studies assessing vibration training or stochastic resonance therapy focus on the musculoskeletal and neuromuscular aspect of the training. No study was found with the aim of investigating the cognitive functions of healthy individuals by using vibration training in general and the VGD applying local stochastic vibration in particular.

2. Research Aim

Considering that a big number of children and adolescents do not reach the recommendations of PA given by the WHO in the last years and even more during the COVID 19 pandemic with the extensive negative consequences on physical, mental, psychosocial and cognitive health and regarding the general effects of vibration training in different age groups, conditions and concerns it seems to be interesting to combine regular PA with vibration training, more over with stochastic vibration training, to observe the effects on selected parameters in adolescents. The study was planned before COVID 19, and now (after COVID19) an intensification of the negative phenomena concerning sedentary lifestyle can be observed.

The concern to stimulate cognitive functions especially in children, adolescents and young adults is an extremely important issue in the modern world, where speed and precision of action are of key importance both for school achievements and high social position. At the same time, new technological achievements appear. Their presence does not remain indifferent to everyday life, but in some situations, it is even a challenge that, on the one hand, must be faced, and on the other hand, the emerging phenomena must be examined in order to assess its impact on everyday activities, including cognitive functioning.

As mentioned before sedentary behavior and screen time in adolescents has increased whereas MVPA has decreased. In order to find short, attractive and effective exercise programs which easily can be introduced in schools and educational institutions and also can be carried out in the recreational time by adolescents alone or in groups this study undertook an analysis of the impact of a device generating local stochastic vibration during moderate-intensity physical exercise on selected cognitive functions important from the point of view of operational efficiency. The VGD has been chosen because of its particular characteristics of creating local stochastic vibration while exercising, its physical parameters (size, color and weight) and the practicality in regard to the requirements of educational institutions which means individual equipment of the participants for simultaneous exercise execution in the group, possibility to disinfect the equipment after individual use and space-saving and easy storage between exercise sessions.

The purpose of this research was to find out whether there were differences in the level of the cognitive functions of students aged 15 and 16 years who participated at two different exercise intervention programs (with VGD versus without VGD) compared to a group of teenagers without any additional exercise intervention program.

In order to achieve the purpose of the study, the following research questions were asked:

1) Is there a difference in the level of selected cognitive functions between students participating in the 10-week intervention program with additional PE lessons compared to students who did not participate in these lessons? If so, which one?
2) Is there a difference in the level of selected cognitive functions between students participating in a 10-week intervention program with additional PE lessons, and exercising with a local vibration device compared to students doing the same exercises without the use of vibration?
3) Does participation in a 10-week intervention program with and without additional exercise with a VGD make a difference in changes in cognitive function? If yes, which functions are affected and the nature of the changes.
4) Which cognitive functions affect concentration performance in the groups participating in the intervention program (with VGD vs without VGD) compared to the control group?

3. Materials and Methods

3.1. Study enrollment

Preparation for the research project took place in several stages (see fig. 8). First, it was presented at a meeting with the Bildungsdirektion des Bundeslandes Oberösterreich, which gave a positive opinion of the research proposal presented. Then the research scheme and its expected results were presented to the BAfEP Steyr director. After reviewing the project, she agreed to carry out the research at the school under her authority. Since the project required people to help, so in the next step the research was presented at a conference to BAfEP Steyr teachers, who were introduced to the project and learned the main information. Of those present, four teachers agreed to be involved in the testing and the PA program (they were invited to lead the exercise and vibration group and help with the testing procedure).

The final step before the project began was its presentation to all, that means 88 students aged 15–16 from BAfEP Steyr (Fig. 8). Presentation was very detailed and included inclusion and exclusion criteria, the purpose of the study, methodology and expected outcomes.

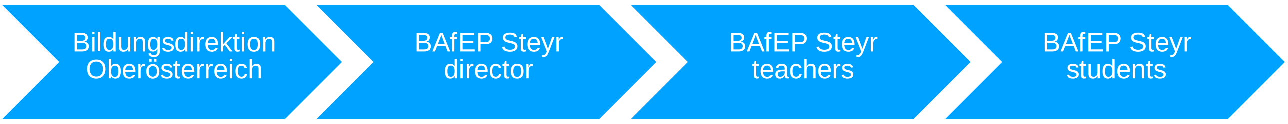

Figure 8: Stages prior to the beginning of the recruitment of students to participate in the study

The inclusion criteria were as follows:

- The age of the subjects (15–16 years), obtaining informed consent of parents/guardians for participation in the study.
- The exclusion criteria were possession of a certificate of dyslexia, dyscalculia or ADHS and any other attested physical or mental health disorder.

Students invited to the project were randomly assigned (1:1 randomization) to three groups: 1) Control Group "CG" (n = 25), 2) Exercise Group "EG" (n = 29) and 3) Vibration Exercise Group „VEG" (n = 34). Students' parents were asked to give their written consent for participation of their children in the study. In some cases (n = 12) parents did not accept participation at the project. This resulted in a change in the size of each group as follows: CG n = 22, EG n = 25, VEG n = 29. Not all included students were present at both pre- and posttests, although they participated for 10 weeks. This resulted in a further reduction of the sample size, which amounted to: in CG n = 20, in EG n = 22, in VEG n = 27. The final drop-out rate was therefore 21.5%. The study enrollment procedure is shown in Fig. 9.

Both girls and boys were included in the study, as allowed by the requirements of the tests used to diagnose the level of cognitive functions (see the methods section).

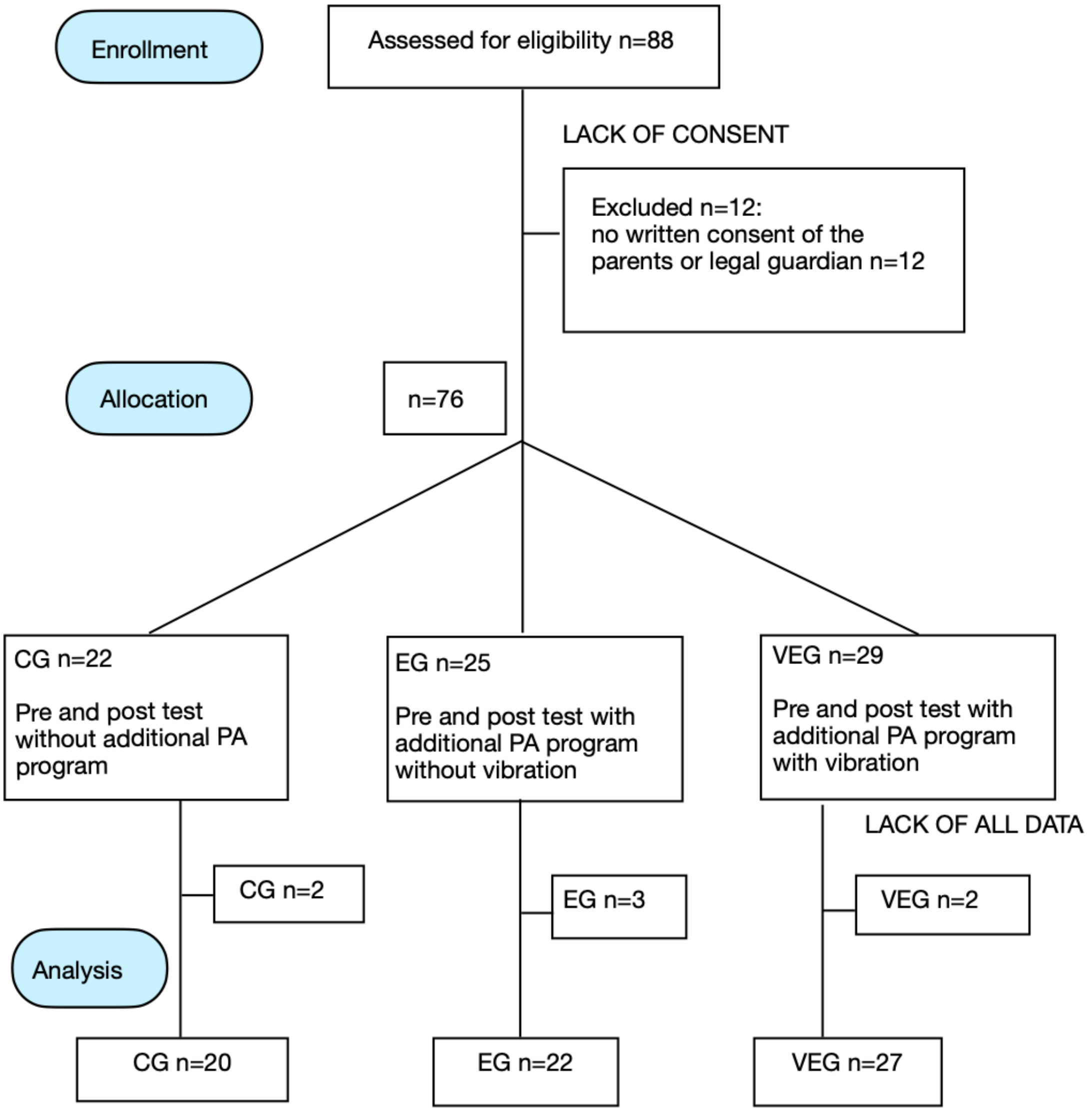

Figure 9: Flowchart of study enrollment, allocation and analysis

The project was based on the Consolidated Standards of Reporting Trials (CONSORT) guidelines. The ethical approval of the study protocol was provided by the Bioethical Committee at Opole Medical School in Poland (24 October 2016, No. 44/2016), in accordance with the Helsinki Declaration.

3.2. Study procedure

The subjects participated in a 10-week intervention exercise program that ran from September to December 2018. During this time, students followed the normal program of physical education classes, students EG participated twice a week in additional physical education classes, and students VEG participated twice a week in additional physical education classes using a vibration-generating device (VGD). The exercises were the same and were performed by the EG and were performed in the same order; the only difference was performing exercises while holding the vibration generating devices in the VEG group. Exercise performed comprised simple movements of moderate intensity. Participants were instructed how to hold the equipment properly and how to perform the correct swinging movement in different planes whilst maintaining proper body posture. During the session each participant had their own VGD.

All exercises were demonstrated and performed by certified teachers and participants were asked to copy each movement, moreover, the exercises with the use of VGD were conducted by teachers who were carefully introduced in the training and obtained the confirmation of their competence to work with VGD.

The VGD is a handheld spiral tube with 4 steel balls within it. Movement in the sagittal, frontal or horizontal plane (e.g. a swinging motion) sets the metal balls in motion. The movement of the balls creates a vibration from 0 to approximately 460 Hz, which is transmitted through the handles of the tool. The weight of the static equipment is 0.5 kg; however, it can reach up to 5 kg during movement due to centrifugal forces. The handheld vibration exercise equipment used in the study consisted of 3 steel balls (26 g each, diameter = 24 mm) located inside a spiraled tube made of soft (65%) and hard (35%) PVC (internal groove protruding, helix pitch 6.2 mm) and a grip with soft cushioning elements. It has an oval form with a length of 27 cm and a width of 19 cm. The device name “smovey” comes from the three words: “swing”, “move” and “smiley” and the model „smovey neuroVIBE small/light“ has been used in this research (see Appendix 2).

3.3. Methods of assessing cognitive functions

Assessment of the level of selected cognitive functions was conducted on the basis of commonly known and used tests. In the vast majority of their performance did not require the presence of a psychologist, however, where it was necessary, the tests were performed by a psychologist. In other cases, tests assessing the cognitive functioning of students were performed by teachers who participated in a training course demonstrating the correctness of performing the tests.

The following cognitive functions were assessed with the mentioned test procedures:

- Attention, concentration, accuracy and processing speed – d2-R Test,
- Verbal fluency – Controlled Oral Word Association Test (COWAT),
- Verbal working memory and attention – Immediate Free Recall Words (IFRW),
- Numeric memory – Delayed Serial Recall Numbers (DSRN),
- Directional hearing and proprioception – Acoustic Test (AT),
- Sens of touch – Sensitivity Test (ST).

The worksheets used for each test are included in Appendix 3. A description of each test is presented below.

3.3.1. d2-R test

The d2-R test is the revised version of the d2-test developed by Rolf Brickenkamp, Lothar Schmidt-Atzert and Detlev Liepmann with its first publication in 1962. The 2d-test appeared in 9 editions with continuous improvements until it has been revised in 2010 with important changes and the designation d2-R (Brickkamp et al. 2010).

With the d2-R test attention and concentration can be measured, including visual and sustained attention, mental speed as well as processing, working and perceptual speed and the general concentration performance (Brickenkamp et al. 2010).

This test sheet consists of one A4 sheet in landscape format with 14 lines of 57 characters each, whereby the first and last lines are not considered for the evaluation of the performance. Lines 2–13 are evaluated according to the test evaluation guidelines and can be divided into 4 blocks of 3 lines each for even more detailed examination.

The task for participants in the study is to mark all characters with a "d" and 2 apostrophes either above the letter, below it, or above and below it. In addition to the letter "d", there is also the letter "p" as a distractor and different numbers of apostrophes (1, 2, 3 or 4) placed above, below or above and below.

Since 2010, the revised version of the d2 test (d2-R) has included a quick reference guide. This includes the query of important data about the study participants and 2 practice lines with detailed instructions on how to perform the test correctly.

Subjects have exactly 20 seconds to complete each line on the test sheet, after which they must move to the next line and continue here. The total time required to complete the test is 14×20 seconds, that means 4 minutes 40 seconds.

For the evaluation of the results, the following data are determined per line, per block and in total:

- Number of Processed Target Objects (PTO), which means the number of marked characters
- Number of Omission Errors (OE), which means all characters „d“ with 2 apostrophes which should have been marked but were not
- Number of Confusion Errors (CE), which means all characters except „d“ with 2 apostrophes which have been marked but should not

The Concentration Performance (CP) is represented by specifying total PTOs minus OE and CE.

The test evaluation includes an evaluation sheet in which all data can be entered. In addition, the number for Error Percentage (E%) is determined by the following formula:

$$E\% = (OE + CE)/PTO \times 100,$$

which refers to the diligence and accuracy in test processing.

In the evaluation form there is a specific field for transferring standard values for E%, PTOs and CP using a table according to age groups.

After entering the standard values of each test person in a coordinate system, where the standard values for PTO are noted on the x-axis and the standard values for E% on the y-axis, a view with 4 quadrants is obtained, which provides comparable information about the working style in test processing of this person.

In this case, the d2-R test was conducted as a paper and pencil test, since 2017 it exists also as an online test with digital scoring. It is available in 14 languages and is designed in the class of psychological performance tests for people aged 9–60. Only designated persons with appropriate education in the field of psychology, pedagogy, etc. can purchase and use the test.

3.3.2. Controlled Oral Word Association Test (COWAT)

Verbal fluency was assessed with use of COWAT (Controlled Oral Word Association Test) (Lezak et al. 2012). It is used to test the level of verbal fluency, which is understood as the skillful selection of words encoded as a result of linguistic experiences. The participant's task is to say as many words as possible related to the given category (initial letters of words) within a one minute time period. COWAT is a very good indicator of executive functions associated with the frontal lobes and possible semantic constraints associated with the temporal lobes (Micelli et al. 1981).

The administration of the word fluency test had to be done in written form in the 3 groups. All participants had the instruction to write down as many words as possible with the given initial letter at the same time, excluding proper nouns, numbers and words with the same suffix. So not only the finding of the words was asked but also the skills of writing the words down as fast as possible within the requested time period of one minute. Considering this additional task, the test required further skills from the participants and was applied in this case as a written variant of COWAT for all participants to ensure comparability within the group.

3.3.3. Immediate Free Recall Words (IFRW)

The free recall test is a basic paradigm of memory tests in experimental psychology. The participants study a list of items presented one at a time for a short duration and report as many as possible in any order (Franklin et al. 2002). It is called an immediate free recall if the reproduction of the items takes place immediately after the study period of the list in contrast to a delayed recall of the items (delayed free recall). With this method the performance of the working memory can be assessed.

In this free recall test 20 randomly selected words without any context have been projected one at a time to all participants sitting in one room equipped each with paper and pencil. Different types of words were used. The projection of the words was visible for 60 seconds, during which time as many of them as possible had to be memorized. After this time the words were faded out and the participants were asked to write down all the words they have memorized in any order immediately after the list had disappeared.

The process was repeated 3 times, each time with different words. The average of the memorized words of all 3 runs was used for evaluation.

3.3.4. Delayed Serial Recall Numbers (DSRN)

Another type of recall tests are serial recall tests. The difference to free recall tests is that the order of the reproduced items (numbers, words, pictures…) has to be the same as on the list shown before to the participants of the study. It is actually the oldest memory paradigm used by Francis Nipher in 1878. The recall of a telephone number is a perfect example of a serial recall: both, the memory and the order of the items are critical (Roediger et al. 2005).

Serial recall is a method to get information about the performance of the short-term memory for serial orders which is the foundation of many acts of higher cognition (Hurlstone, 2022).

Also, in the field of serial recall tasks there are different types of recall forms: the immediate or the delayed reproduction of the items. Concerning the delayed form of serial recall tests the recall is asked after a short time of rest or distraction which varies from a few seconds to 30 minutes or even more.

The delayed serial recall test of numbers is similar to the digit span test which asks people to recall a certain series of numbers. The longest list of digits they can remember is called the digit span and gives information about the memory storage capacity. In 1956 A. Miller observed that an average young individual was able to memorize 7 (±2) items in an immediate recall (Miller, 1956).

The average time frame of the short-term memory seems to be between 15 and 30 seconds (McLeod, 2009) and the longer the delay the less information is recalled (McLeod, 2018). According to the findings of Atkinson and Miller the short-term memory has a limited storage capacity of 7 items (±2) and a limited time frame while information can be reproduced of about 15 to 30 seconds (Atkinson et al. 1968).

Regarding these findings about the short-term memory the delayed serial recall test in this study was designed as follows:

Study participants saw 6 numbers in a row separated by hyphens on a projection all at the same time. They had 3 seconds to remember this series of numbers before it disappeared. After that, they hat to wait 20 seconds and then write down the series of numbers from memory on a piece of paper.

The process was repeated 6 times, each time with a different series of numbers. The participants were required to write down the correct numbers in the correct order.

In the evaluation, the average of all correct number sequences from the 6 runs was taken into account.

This proceeding is intended to provide the best possible information about short--term memory performance in the processing of both: the number of digits asked in the correct order and the delayed recall of 20 seconds.

3.3.5. Acoustic Test (AT)

The acoustic test is used as a variant of the neurological test for hearing. In the original test a noise is produced by rubbing the fingers on the right and left ear of the subject. The noise should be perceived by the person and gives indication about the person's hearing and the function of the 8^{th} cranial nerve (nervus vestibulocochlearis) (Delank et al. 2010).

In the test setting of this thesis, the original test was expanded: the capacity of directional hearing with the exact localization of the source of noise is measured, as well as proprioception. This was designed as follows:

The same acoustic signal is generated by a device at each of 5 different, fixed positions that can be reached with the subject's hand. The subject closes his eyes and let both arms hang next to his hips. After hearing the acoustic signal, the subject reaches for it with closed eyes and holds the hand with the touching fingertips at the position where he or she suspects the source of the sound.

The distance of the closed fingertips to the noise source is measured. The closer the fingertips to the device with the noise source (the smaller the distance), the more accurate the acoustic orientation and perception.

The mean value of the 5 positions was used for the evaluation.

3.3.6. Sensitivity Test (ST)

The purpose of the sensitivity test is to identify the ability to perceive different surfaces through the sense of touch and tactile acuity. There are different approaches to test the abilities of the sense of touch, e.g. different shapes with different surfaces are used, which have to be felt and identified with the fingertips (Cheeseman et al. 2016). The physical contact with object surfaces stimulates the subcutaneous mechanoreceptors and lead to the appropriate perception and awareness through the activation of the associated areas within the cerebral cortex (Norman et al. 2013).

The sensitivity test involves palpation and collection of pairs of sticks with identical surfaces that are contained in an opaque pouch so that they cannot be seen. Participants are asked to find as many identical pairs of sticks as possible within 2 minutes and place them side by side outside the opaque cover.

3.4. Statistical analysis

The collected results were subjected to statistical analysis. The normality of the distribution of individual variables was assessed using the Shapiro-Wilks test. This was followed by a visual assessment of the normality of the distribution presented by means of a histogram; this is in accordance with the recommendations of the authors of Statistics (www.statsoft.pl). They consider that the evaluation of the normality of a distribution cannot be completely replaced by tests, so the use of visual assessment is as justified as possible. The normal distribution was held by the results of all tests used: the d2-R, COWAT, IFRW, DSRN, AT and ST. In the case of parameters for which there was no basis for rejecting the hypothesis of a normal distribution, mean values (x) and standard deviation (SD) were calculated and parametric tests were used in the subsequent procedure. The relationships between the explained and explanatory variables were evaluated using the Spearman correlation.

The strength of correlations was interpreted according to the following scheme:

- $|r| \geq 0.9$ – very strong correlation,
- $0.7 \leq |r| < 0.9$ – strong dependence,
- $0.5 \leq |r| < 0.7$ – moderately strong dependence,
- $0.3 \leq |r| < 0.5$ – weak dependence,
- $|r| < 0.3$ – very weak (negligible) dependence.

Interpretation scheme after: Hinkle DE, Wiersma W, Jurs SG. Applied Statistics for the Behavioral Sciences. 5th ed. Boston: Houghton Mifflin; 2003.

The variation in mean values of all variables was compared using the Least Significance Differences Test (LSD) for independent samples.

Relationships between CP and other parameters in the study were also calculated using progressive stepwise regression. Regression analysis was used because it is considered an effective method for determining which variables selected from the total variables affect the results of the CP variable. The process of conducting regression analysis makes it possible to determine which factors are most influential in explaining the outcome of the explained variable, and how the factors taken into account affect each other. The explanatory variables were PTO, AT, ST, IFRW and DSRN while the explained variable was the results CP obtained in the d2-R test. The use of the regression method allowed to determine the optimal set of explanatory variables (including interdependencies between them) that would best predict the performance of the CP variable (describing the general Concentration Performance). We chose to include in the model above mentioned explanatory variables analyzed in the study.
The regression equation determined was of the form:

$$\text{Resulting trait} = b_0 + b_1x_1 + ... + b_px_p + e,$$

whereby:

b_0 – the free expression of the regression equation,

$b_1, \dots, b_p$ – coefficient of the regression equation,

$x_1, \dots, x_p$ – independent variables,

e – independent random errors.

The coefficient of determination R^2 was used as a measure of the relationship between the explanatory variables and the explained variable. Its value multiplied by 100% determines how many percent the explanatory variables explain the variation in the results of the explained variable. Also included in the analysis was the standardized partial regression coefficient beta (ß), which tells how much the explanatory variable will change due to a standardized change in the explanatory variable (Stanisz 2006).

Statistical significance was assumed at the level of $p < 0.05$ for all the applied tests. Calculations were performed using Statistica v. 13.1 software by StatSoft (Wroclaw, Poland) in the Biostructure Research Laboratory of the University of Health and Sport Sciences in Wroclaw, certified according to ISO 9001.

4. Results

This chapter is devoted to analyzing the results obtained from the research conducted.

For the evaluation all results from the participants meeting the inclusion criteria, absolving the pre- and posttest and attending the 10-week exercise intervention program were taken into account. No differences have been made between female and male participants because according to the description and the guidelines of the tests assessing the cognitive functions, results can be evaluated equally without gender-specific differentiation.

The chapter is divided into three parts, with the first part presenting the differences between the results of each variable, the next part of the chapter presented simple relationships between the variables considered, and the third part was devoted to determining the variables that most explain the results of CP. In each case, these analyses were conducted for both pre- and post-study results.

4.1. Changes in the level of cognitive function of CG, EG and VEG students in intergroup comparisons

In this section the variation in mean values of the results of all participants in the 3 groups (CG, EG, VEG) are compared using Least Significance Difference (LSD) test for independent samples. The variables of all tests within the groups were compared from the pretest versus the posttest, as well as the variables of all tests in comparison of the pretest to the posttest of the individual groups among each other. Statistically significant differences ($p < 0.05$) are marked with bold numbers (see Table 1).

Table 1: LSD Test (Least Significant Differences); Probabilities for post-hoc tests

Variable	LSD Test; Probabilities for post-hoc tests, p- values								
	pretest vs posttest			CG vs EG		CG vs VEG		EG vs VEG	
	CG	EG	VEG	Pre test	Post test	Pre test	Post test	Pre test	Post test
Test processing speed (PTO)	**0,0000**	**0,0000**	**0,0000**	**0,0098**	**0,0452**	0,5882	0,1137	**0,0210**	**0,0002**
Omission Errors (OE)	0,8589	0,5468	**0,0197**	0,3747	0,5179	0,0626	0,5384	0,2984	0,9572
Confusion Errors (CE)	0,8055	0,3460	0,2305	0,1621	0,6214	0,9657	0,4918	0,1323	0,8456
Concentration Performance (CP)	**0,0000**	**0,0000**	**0,0000**	**0,0213**	0,0653	0,2323	0,2512	0,1935	**0,0014**
Diligence in task processing (E%)	0,5541	0,3051	**0,0017**	0,3435	0,4800	0,0707	0,9008	0,3615	0,5156
Standard values PTO	**0,0000**	**0,0000**	**0,0000**	**0,0075**	**0,0340**	0,5664	0,2102	**0,0175**	**0,0003**
Standard values E%	0,5237	0,1460	**0,0042**	0,2780	0,5067	0,2494	0,9575	0,9682	0,4270
Verbal fluency (COWAT)	0,2405	**0,0000**	**0,0000**	0,6865	**0,0084**	0,6306	**0,0012**	0,3252	0,5171
Verbal memory test (IFRW)	**0,0193**	**0,0001**	**0,0000**	0,5743	0,9868	0,9093	0,3953	0,6099	0,3590
Numeric memory test (DSRN)	0,4448	0,1095	0,3653	**0,0181**	0,0562	0,2656	0,2496	0,1399	0,3644
Acoustic Test (AT)	0,5544	**0,0063**	0,1573	0,1730	0,2908	0,3740	**0,0236**	**0,0192**	0,2372
Sensitivity Test (ST)	0,1410	**0,0124**	**0,0075**	**0,0354**	0,1703	0,0684	0,2526	0,6744	0,7526

CG – Control Group, EG – Exercise Group, VEG – Vibration Exercise Group

4.1.1. Results of the d2-R test

Number of Processed Target Objects (PTO)

The results of PTO obtained by the participants show the number of processed target objects and its value depends on the processing speed of information, which means how fast participants can distinguish between correct information and distractors introduced into the study, and how these distractors are able to cause errors bypassing correct information.

As well as at the pretest as well as at the posttest the lowest number of PTO was reached by the EG compared to the CG and the VEG. The difference was statistically significant in pre- and posttest (see Table 1 and Fig. 10).

Participants in all groups statistically significantly improved their posttest scores. In the posttest, among the three groups, the lowest number of PTOs was observed in the EG group, while the highest number was observed in the VEG group. Also notable is the highest percentage improvement in performance in the VEG group, which reached almost 30%.

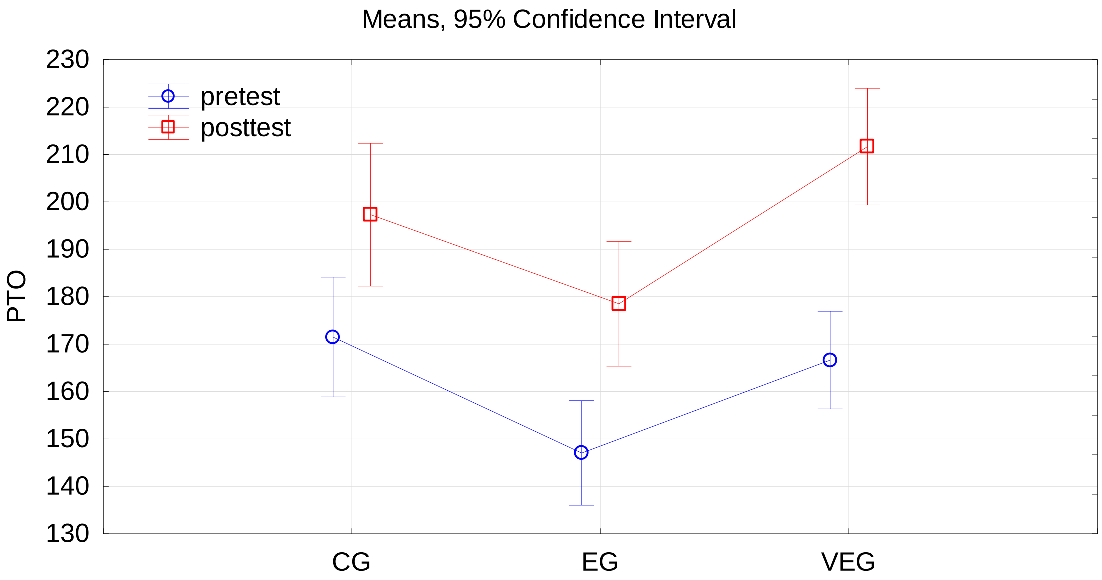

Figure 10: Pre- and posttest results of PTOs in CG, EG and VEG

Omission Errors (OE)

Omission errors mean target objects that were not recognized and marked as such as part of the PTOs from the participants of the study. Participants could not distinguish them as correct target objects from the distractors.

No statistically significant differences occurred between the three groups neither in the pretest nor in the posttest. At the posttest the number of omission errors declined in all groups but only in the VEG in a statistically significant way of more than 30% (see Table 1 and Fig. 11).

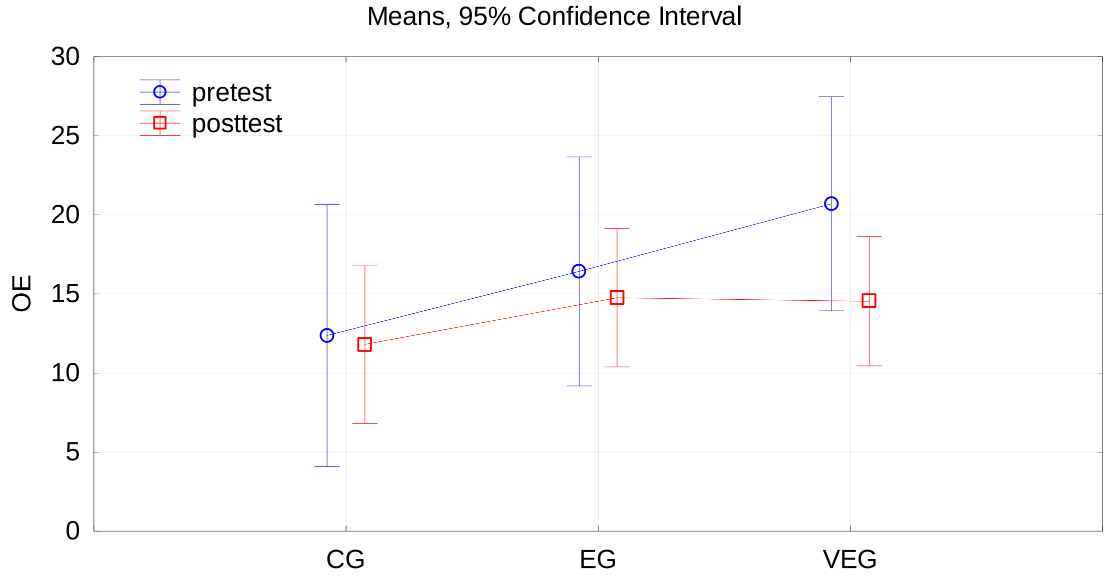

Figure 11: Pre- and posttest results of OEs in CG, EG and VEG

Confusion Errors (CE)

CE are the incorrectly marked distractors within all PTOs. Participants were not able to distinguish them as incorrect information from the correct target objects within the specified time (Fig. 12)

No significant differences neither between the 3 groups in the pretest and in the posttest can be observed nor statistically significant changes after the 10 weeks intervention program can be found by comparing the results of the pre- and posttest within the same groups (Table 1). Remarkable is that only in the EG the number of CE increased at the posttest compared to the pretest, the other groups showed a not statistically significant decline of CE at the posttest where especially the VEG with an improvement of approximately 25% as the group with the fewest CE in the posttest is particularly evident.

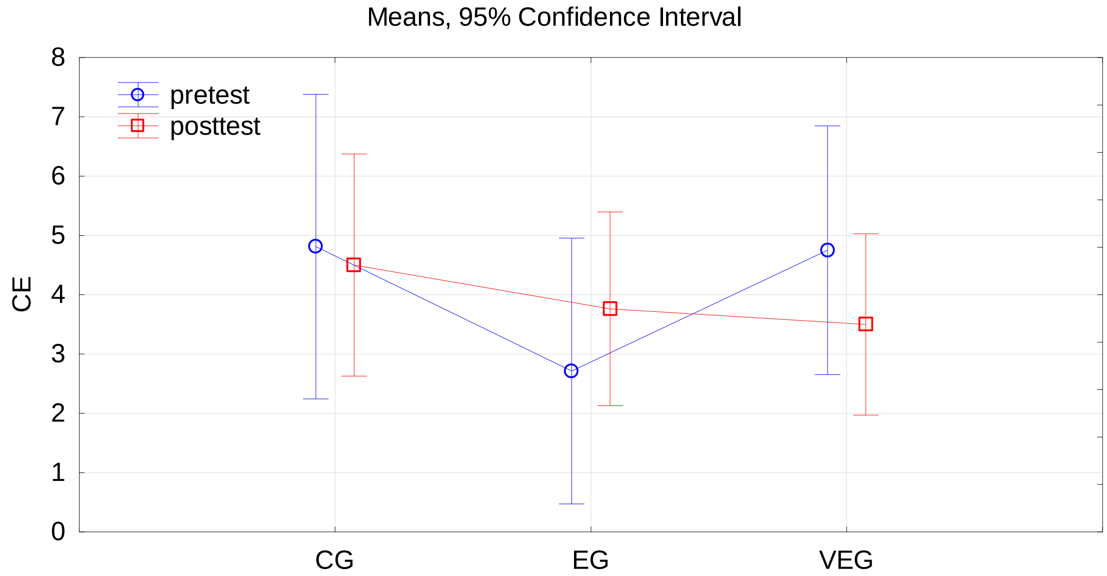

Figure 12: Pre- and posttest results of CEs in CG, EG and VEG

Concentration Performance (CP)

The CP consists of the number of processed target objects minus the number of omission and confusion errors (CP = PTO – [OE + CE]). It represents the number of correct identified items without OE within the specified time and is the parameter for illustrating the CP.

A significant difference could be observed at the pretest between the EG with the lowest CP of all groups compared to the CG with the highest score of CP and a difference of about 18% in comparison to the results of the participants of the EG (see Table 1 and Fig. 13).

The obtained results at the posttest compared to the pretest show a statistically significant increase of the CP in all groups which means an improvement of about 15% for the CG, about 20% for the EG and more than 26% for the VEG.

Also notable are the results of the posttest of the EG with a very similar score to the results of the pretest of the CG, which means that the participants of the EG reached a comparable score of CP after the 10-week intervention program than the CG had before.

The highest score of CP at the posttest was reached by the VEG with also the highest improvement in percentage compared to the pretest (more than 26%).

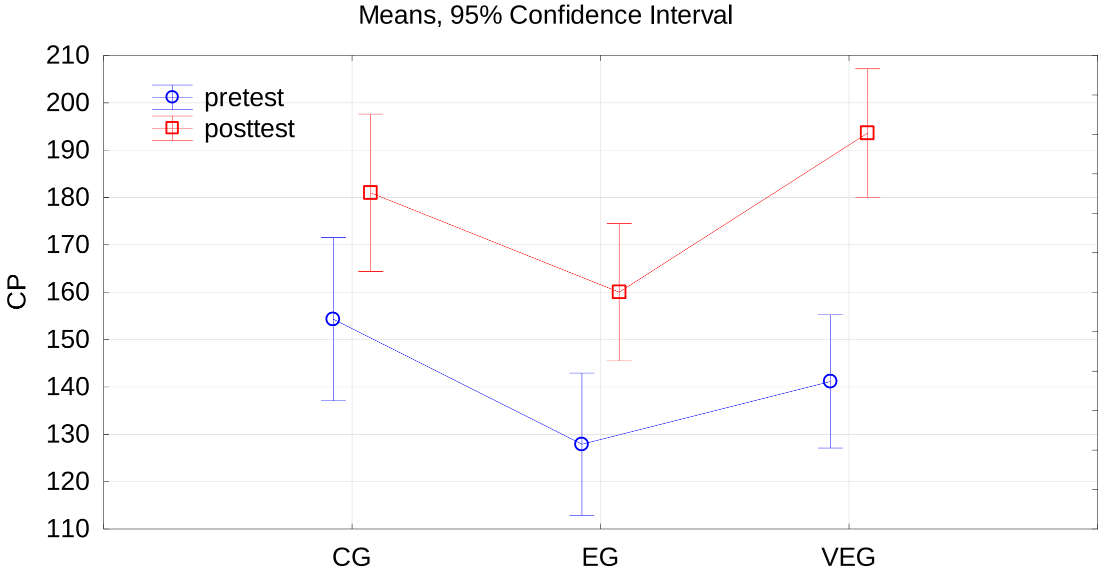

Figure 13: Pre- and posttest results of CP in CG, EG and VEG

Diligence in test processing (Error Percentage = E%)

E% refers to the diligence (accuracy) in processing the test tasks and is calculated with the following formula: E% = ((OE + CE)/PTO x 100. No significant differences appeared between the 3 groups either in the pretest nor in the posttest (see Table 1 and Fig. 14). A decrease in the E% can be determined in all 3 groups in the posttest, a statistically significant improvement can only be noted in the VEG group, which achieved nearly 50% in comparison to the pretest significant improvement can only be noted in the VEG group, which achieved nearly 50% in comparison to the pretest.

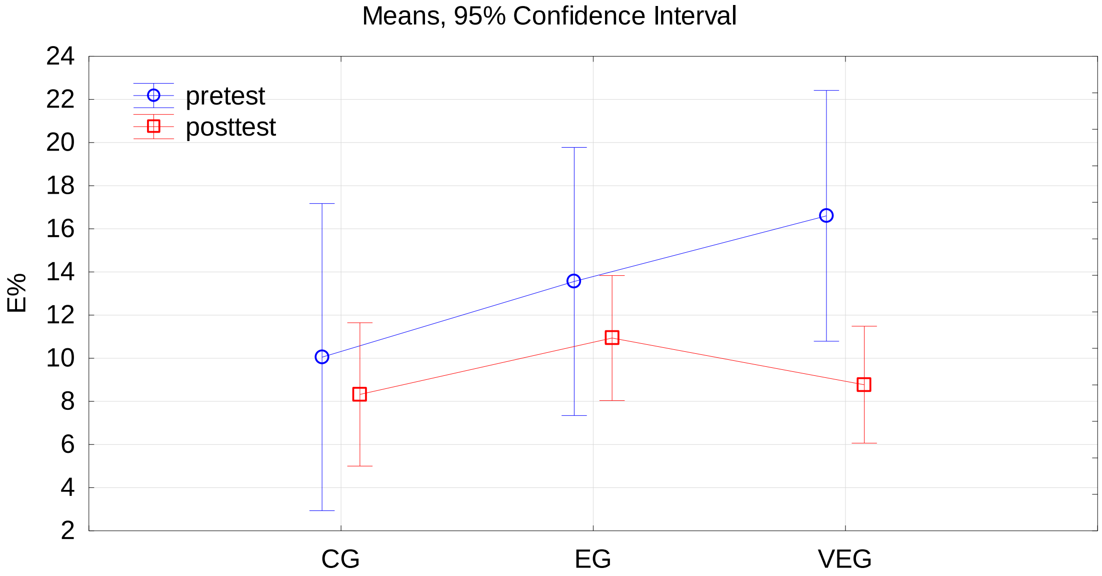

Figure14: Pre- and posttest results of E% in CG, EG and VEG

Working style of test processing

In order to obtain a standardized representation of the working style by doing the d2-R test in different age groups and regions, tables with standard values were created and added in the test manual.

The data for diligence in test processing (standard values E%) are shown on the vertical axis and the standard values for the working speed (PTO) on the horizontal axis (see Fig. 15). The graphic representation for the evaluation of the working style results from these two components which have to be interpreted together for a meaningful result regarding the working style. The higher the score for the standard value E% the greater the diligence (accuracy), the further the score to the right on the PTO axis the faster the working speed.

Significance of the quadrants:

- Quadrant 1 (bottom left): results of those individuals are characterized by little diligence and slow speed.
- Quadrant 2 (bottom right): results of those individuals are characterized by little diligence and fast speed.
- Quadrant 3 (top left): results of those individuals are characterized by great diligence and slow speed.
- Quadrant 4 (top right): results of those individuals are characterized by great diligence and fast speed.

The working style is determined using the standard values for E% and PTO and the results are entered in the specified coordinate system. The position of the points in the individual quadrants provides information as well about the diligence (accuracy) in test processing and the speed in test processing.

Concerning the standard values of E%, which refers to the accuracy in the working process, in the pretest no significant differences can be discovered between the 3 groups (see Table 1). Noteworthy is the low accuracy of 4 subjects of the VEG at the pretest.

The standard values of the PTO corresponding to the working speed show significant differences between the EG with the lowest values for speed in comparison to the CG and the VEG with remarkably higher number of PTOs (see Table 1 and Fig. 15).

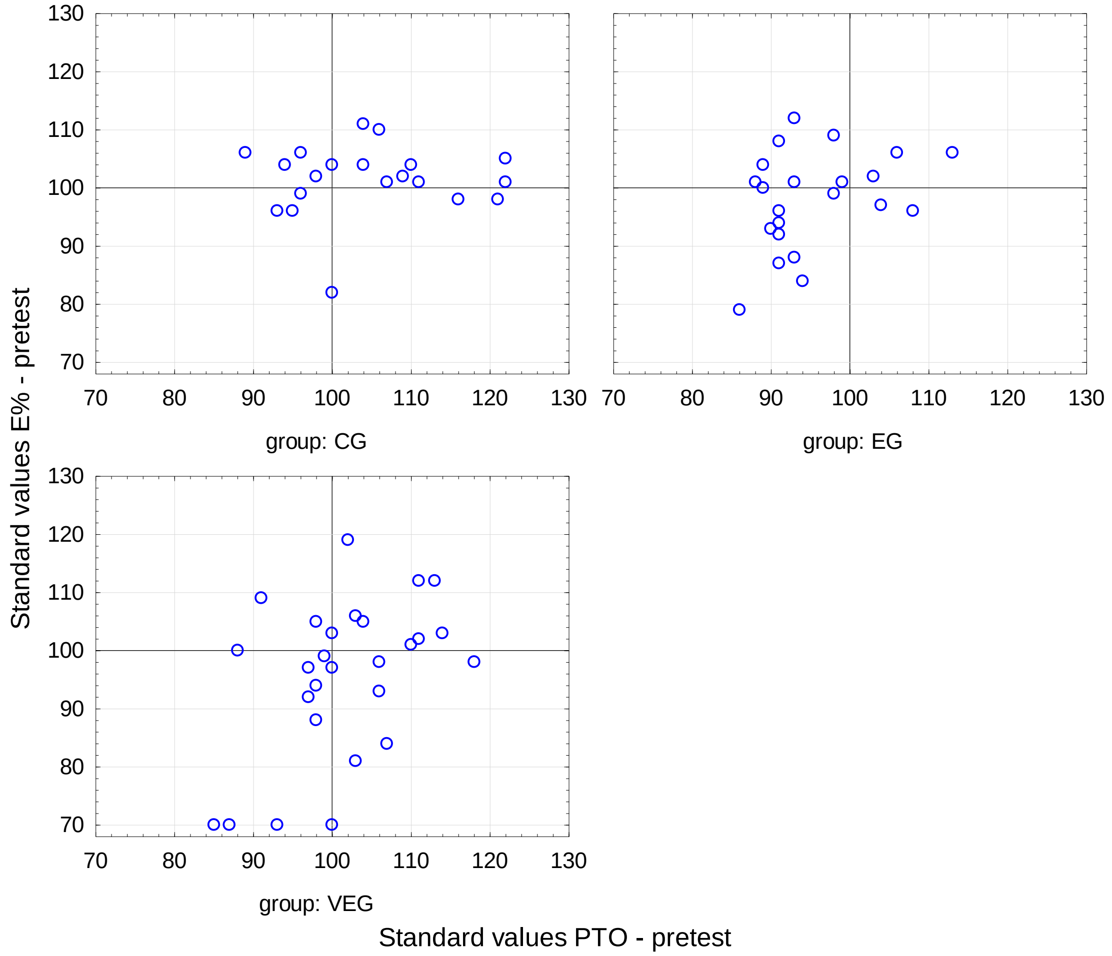

Figure15: Pretest results of working style in test processing in CG, EG and VEG

In the posttest there are no significant differences between the three groups concerning the standard values of E%, the mean in all groups is in the range between 100 and 102 (see Table 1 and Fig. 16).

Comparing the pre- and posttest results of the standard mean values of the VEG there is a significant increase of accuracy. From the 4 subjects with low accuracy (E%) in the pretest there is only one subject with very low accuracy left.

Similar to the pretest results the standard mean values of the posttest of working speed (PTO) show a difference between the EG with the lowest speed in comparison to the CG with higher speed and the VEG with the highest numbers of PTOs corresponding to the working speed.

All 3 groups show a significant increase in working speed comparing the standard mean values of PTOs from the pre- to the posttest after the 10 weeks intervention program (see Table 1). The highest score is achieved by the VEG as well in the standard values for E% as well in the standard values for PTO, which means the greatest accuracy at the same time as the highest working speed.

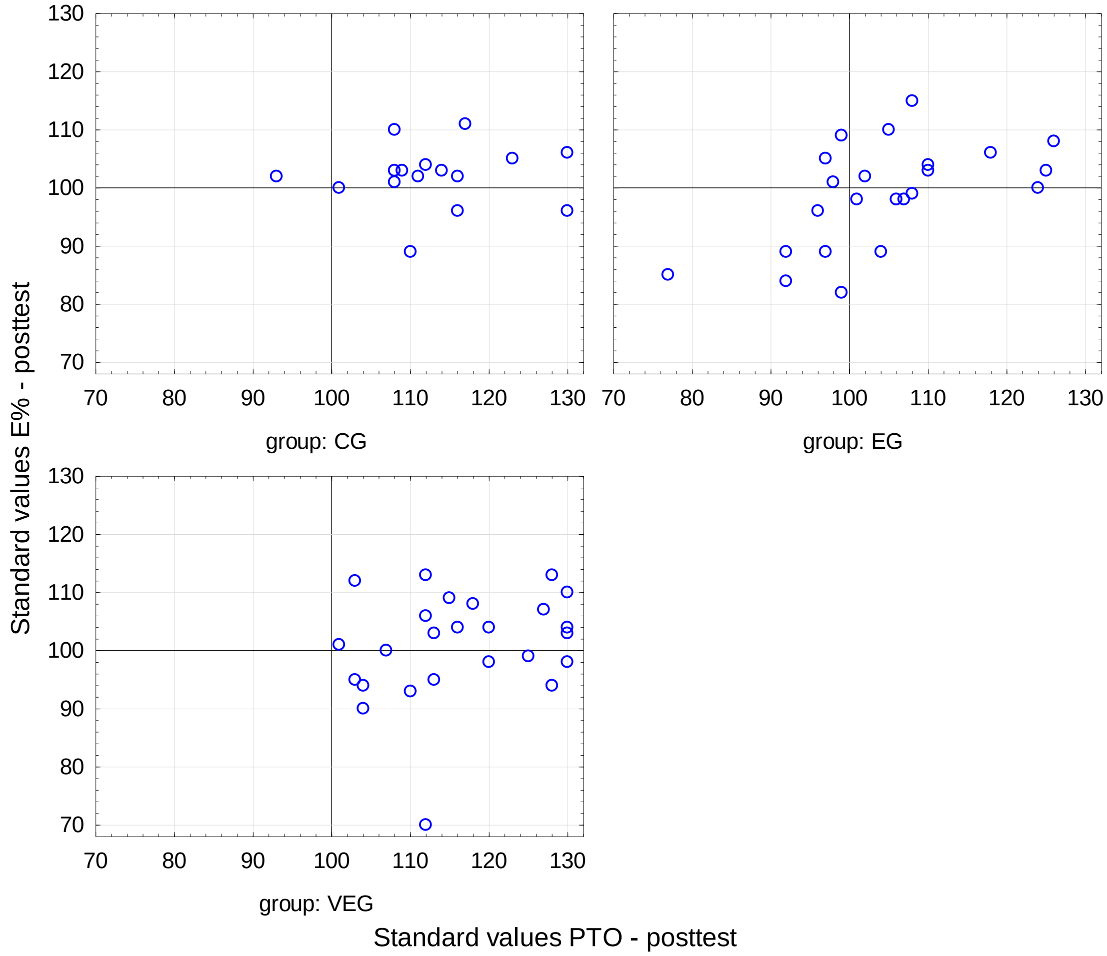

Figure 16: Posttest results of working style in test processing in CG, EG and VEG

From the point of view of work efficiency, the expected results are those in quadrant 4, because they say that the person surveyed works quickly and accurately. So, the question was how the performance of the subjects in each group would change as a result of participation in the 10-week intervention program, and whether there would be an increase in the percentage of test subjects whose posttest scores were in quadrant 4 (diligence in test processing and test processing speed).

At the pretest from all 3 groups, a total of 36% of the participants' results were observed in the 1st quadrant, including 20% from CG, 45% from EG and 41% from VEG.

Results 13% of the participants from all groups appeared in the 2nd quadrant at pretest, including 10% from CG, 9% from EG, and 19% from VEG.

In the 3rd quadrant figured a result of total of 22% of the subjects of all groups with 25% from CG, 32% from EG, and 11% from VEG.

The 4th quadrant was filled with a result of a total of 29% of participants from all 3 groups at the pretest, of which 45% were from the CG, 14% from the EG and 30% from the VEG.

Table 2: Percent of participants' results (CG, EG, VEG) in each quadrant at the pretest

Group	Quadrant 1 bottom left	Quadrant 2 bottom right	Quadrant 3 top left	Quadrant 4 top right	Summary (%)
CG	20,00%	10,00%	25,00%	45,00%	28,99%
EG	45,45%	9,09%	31,82%	13,64%	31,88%
VEG	40,74%	18,52%	11,11%	29,63%	39,13%
Total	36,23%	13,04%	21,74%	28,99%	100,00%

At the posttest from all 3 groups, results of a total of 9% of all participants were in the 1st quadrant (26% of the participants of the EG only).

Results of 33% of the participants from all groups appeared in the 2nd quadrant at the posttest, including 25% from CG, 26% from EG, and 44% from VEG.

In the 3rd quadrant figured results of a total of 6% of the subjects of all groups with 6% from CG, 13% from EG, and 0% from VEG.

The 4th quadrant was filled with results of a total of 52% of participants from all 3 groups at the posttest, of which 69% were from the CG, 35% from the EG and 39% from the VEG.

Table 3: Percent of participants' results (CG, EG, VEG) in each quadrant at the posttest

Group	Quadrant 1 bottom left	Quadrant 2 bottom right	Quadrant 3 top left	Quadrant 4 top right	Summary (%)
CG	0,00%	25,00%	6,25%	68,75%	25,00%
EG	26,09%	26,09%	13,04%	34,78%	35,94%
VEG	0,00%	44,00%	0,00%	56,00%	39,06%
Total	9,38%	32,81%	6,25%	51,56%	100,00%

Changes of the results of the study participants after the 10-week program

For ease of reference the results shown in the tables 2 and 3 and in the figures 15 and 16 will be analyzed separately in individual diagrams.

Due to the importance of the results located in the 4th quadrant (pretest vs posttest change), they are presented in the following order:

1) Description of the 4th quadrant – the most expected outcomes,
2) Description of the 1st quadrant – the least expected outcomes,
3) Description of the 2nd and 3rd quadrant.

The diagram showing the change in the 4th quadrant is described and illustrated first because of its importance concerning obtaining and improving cognitive functions of accuracy and speed in processing tasks which are of high priority of the required skills of today.

Figure 17 shows the modification of the percentage of test participants whose results were found in the 4th quadrant at the pre- and at the posttest in each group and in total. As the working style of these individuals is characterized by great diligence (accuracy) and high speed, results of the participants are expected being found in the 4th quadrant after the 10 weeks training intervention.

Among participants in all groups, there were clear increases in the percentage in the 4th quadrant. From a total of 28,99% in the pretest, 51,65% entered this zone after the 10 weeks, which means an average increase of 22,66% from all 3 groups.

In the CG can be observed an increase of 23,75%, in the EG of 21,14% and in the VEG the largest increase of 26,37% compared to the results of the pretest.

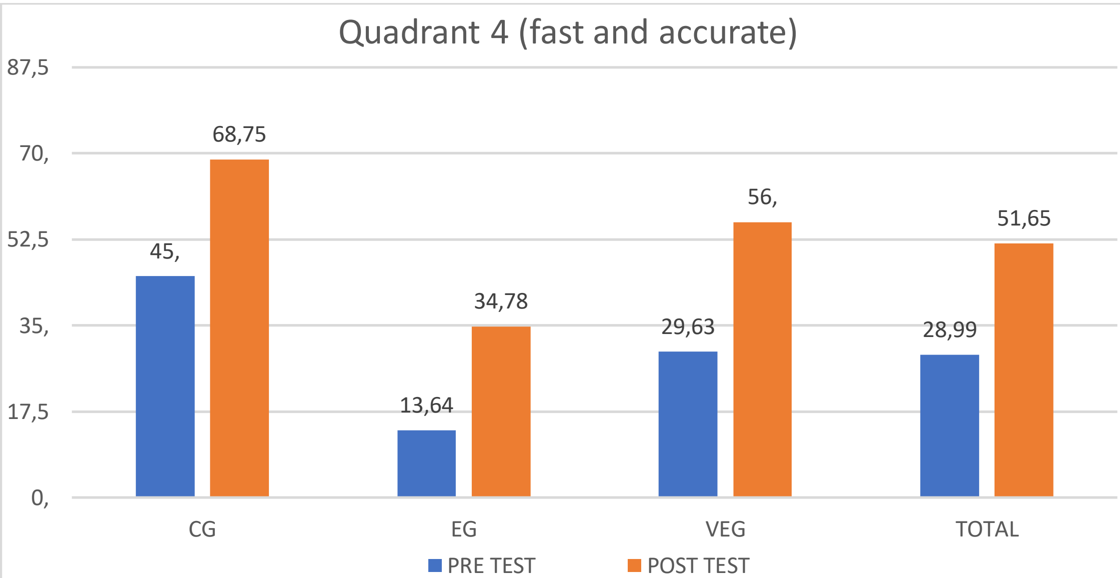

Figure 17: Percent of participants ’results (CG, EG, VEG) in the 4th quadrant at pre- and posttest

The illustration of the modification of the results of the participants concerning the 1st quadrant follows next (Fig.18). The aim of improving cognitive abilities, which can be measured by means of the d2-R test, is also to ensure that as few subjects as possible remain in this sector after the training intervention. A slow and inaccurate working style in processing tasks is not desired neither in academic achievement nor in working performance.

Only 9,4% of all participants remained in the 1st quadrant in the posttest, which is 26,83% less than in the pretest. All individuals in the 1st quadrant in the posttest come from the EG.

There are no participants in either the CG or VEG groups with results in the 1st quadrant at the posttest. For the CG this means a reduction of 20%, for the EG of 19,35% and for the VEG the most significant reduction in the comparison of the 3 groups of 40%, the double of the CG and even more of the EG.

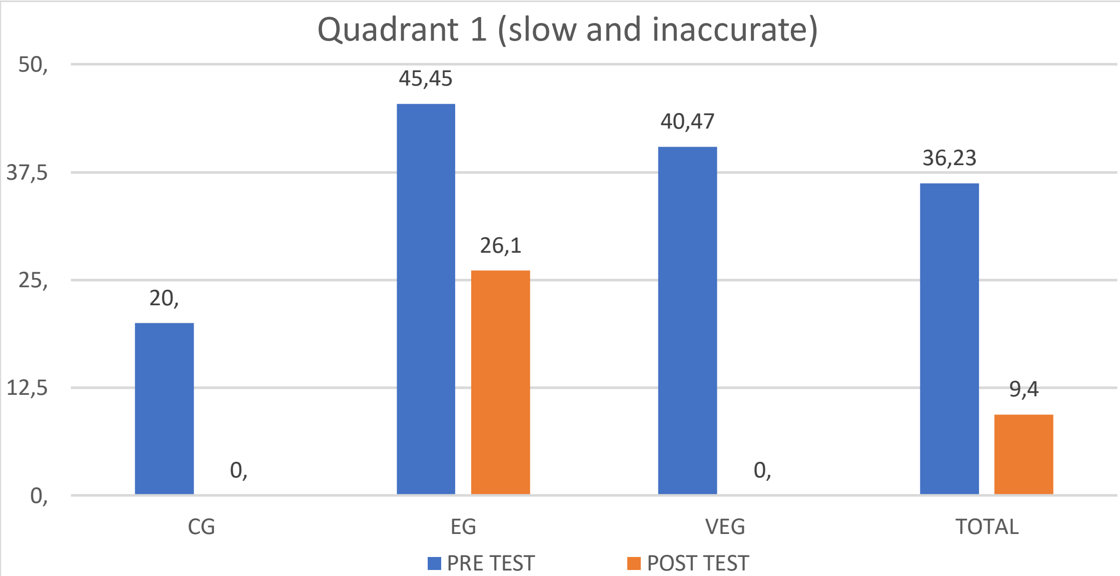

Figure 18: Percent of participants ’results (CG, EG, VEG) in the 1st quadrant at pre- and posttest

In figure 19 the results comparing the pretest to the posttest of all the 3 groups for the 2nd and 3rd quadrants are summarized. The 2nd and 3rd quadrants can be presented together in terms of working style, since one of the two components (speed or accuracy) is fulfilled in each case, but not both. If results are visible in these sectors, the participants of the study worked either quickly or carefully. For the analysis of the results, a separate presentation of both quadrants is not necessary.

If results are visible in these sectors, the participants of the study worked either quickly or carefully. In any case it becomes visible as an improvement if people with results that show up in the 1st quadrant on the pretest end up in the 2nd or 3rd quadrant on the posttest.

Considering the total result of all individuals of the 3 groups, there is an increase in the percentage of 4,28%, noting that the results of the participants of the CG found in quadrant 2 and 3 decreased by 2,75% in the posttest and of the EG by 1,78%. Only the results of the participants of the VEG increased by 14,37% in quarter 2 and 3 at the posttest.

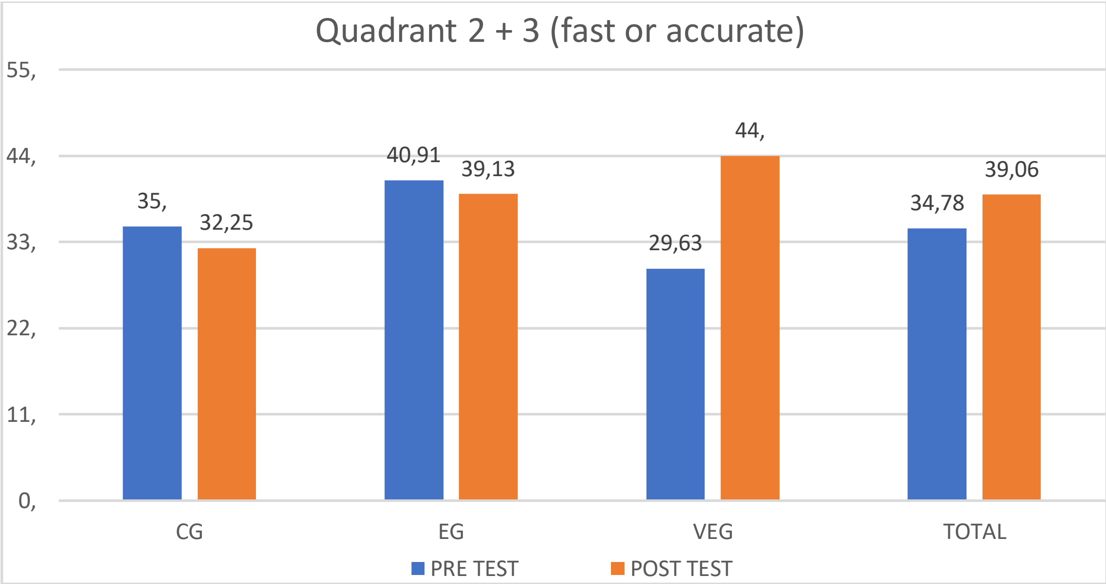

Figure 19: Percent of participants 'results (CG, EG, VEG) in the 2nd and 3rd quadrant at pre- and posttest

4.1.2. Results of the verbal fluency (COWAT)

Verbal fluency was assessed wit use of the Controlled Oral Word Association Test (COWAT), which is an indicator for word fluency.

The results obtained by the three groups at the pretest are very similar, the mean value of produced words is situated in the range between 39 and 41 words in each group (see Table 1 and Fig. 20). Significant differences appear in the posttest between the CG versus the EG and the CG versus the VEG with the CG even deteriorating minimally compared to its pretest as the only group. Statistically significant improvements can be seen in the comparison of the results of pre- and posttest in groups which had additional exercises for 10 weeks, namely both of EG and VEG and are between 11% and 12% for both groups.

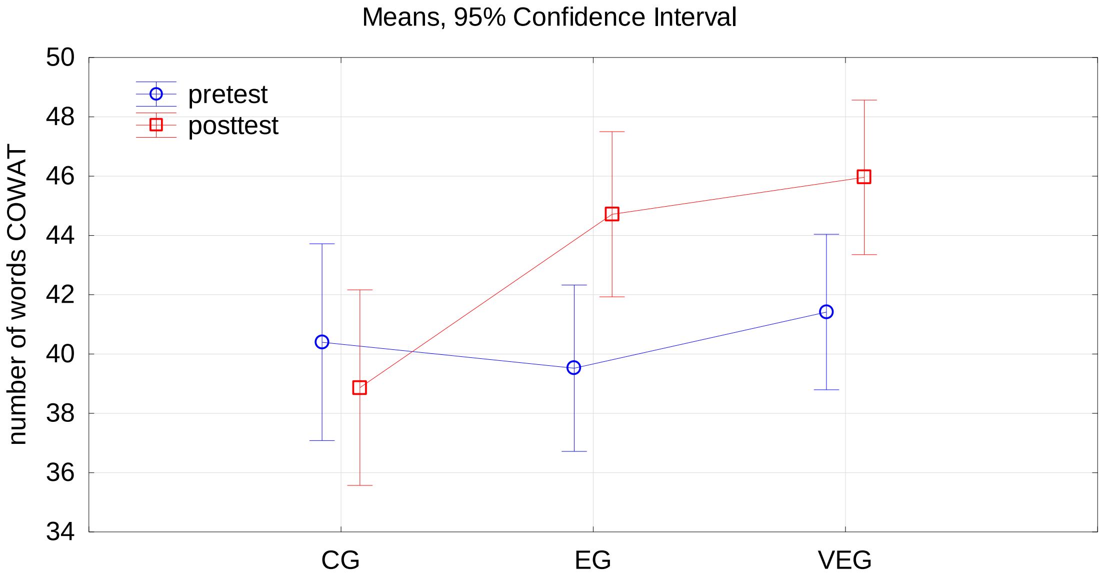

Figure 20: Pre- and posttest results of COWAT in CG, EG and VEG

4.1.3. Results of the verbal memory test (IFRW)

The verbal memory test provides information about the cognitive ability of the working memory to write down determined words after one minute of memorization (Immediate Free Recall Words). At the pre- and posttests no significant differences can be noted within the three groups (see Table 1 and Fig. 21). Each group differs significantly compared from the pre- to the posttest, with the greatest improvement being noted in the VEG with more than 12%.

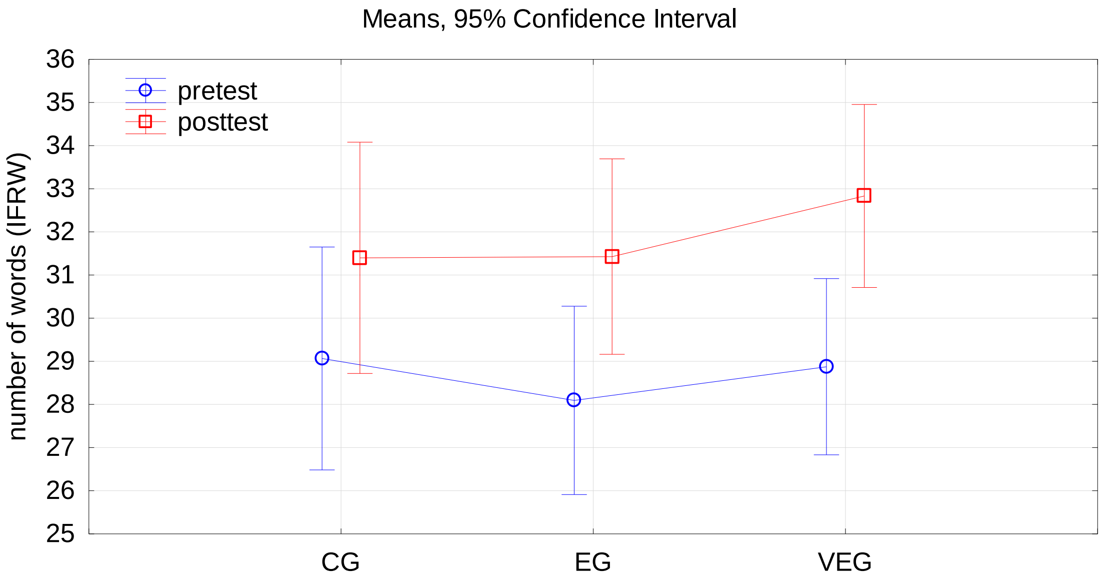

Figure 21: Pre- and posttest results of IFRW in CG, EG and VEG

4.1.4. Results of the numeric memory test (DSRN)

The Delayed Serial Recall Numbers test provides information about the performance of the serial numeric working memory.

At the pretest of the DSRN test there is a significant difference in the results of the values between the EG with the lowest output versus the CG with the highest number of memorized digits (see Table 1 and Fig. 22). Every group was able to improve slightly at the posttest without providing significant changes compared to the values in the pretest of each single group.

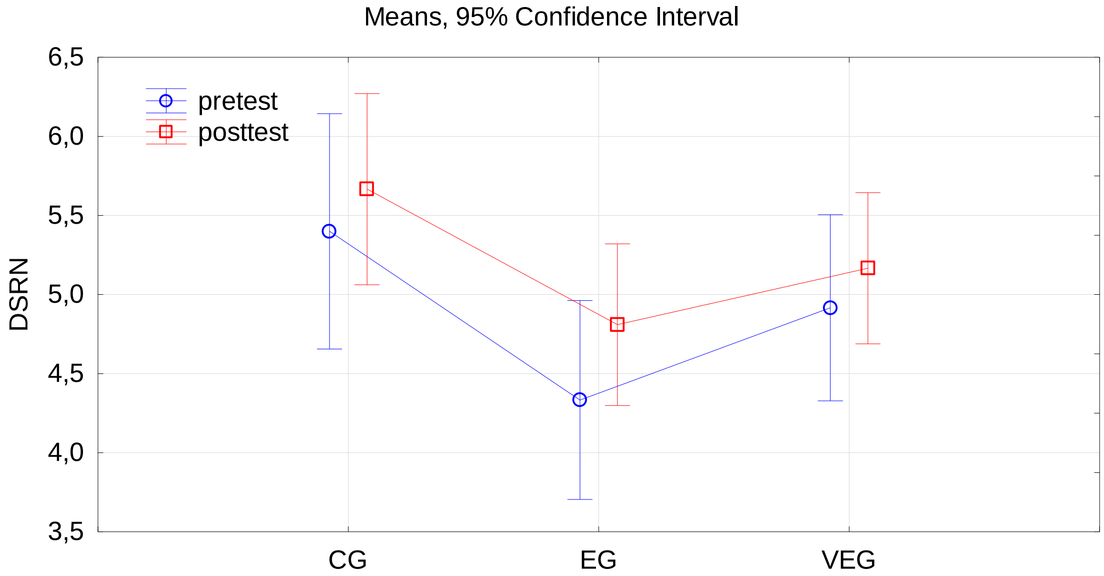

Figure 22: Pre- and posttest results of DSRN in CG, EG and VEG

4.1.5. Results of the Acoustic Test (AT)

The acoustic test measures the ability to locate an identical sound source at different locations near the body and to touch it with the fingertips of one hand with closed eyes. The cognitive functions of the acoustic sense, directional hearing and proprioception can be tested with this method.

In the acoustic test, the EG with the mean values related to the distance from the noise source was furthest away from it in the pretest and differed significantly from the VEG which results indicate that they were closest to the noise source (see Table 1 and Fig. 23).

In the posttest there is a significant improvement in the EG compared to the pretest. Concerning the other groups at the posttest there is only a significant difference between the CG and the VEG which means that the VEG is closer to the noise source and significantly more precise than the CG.

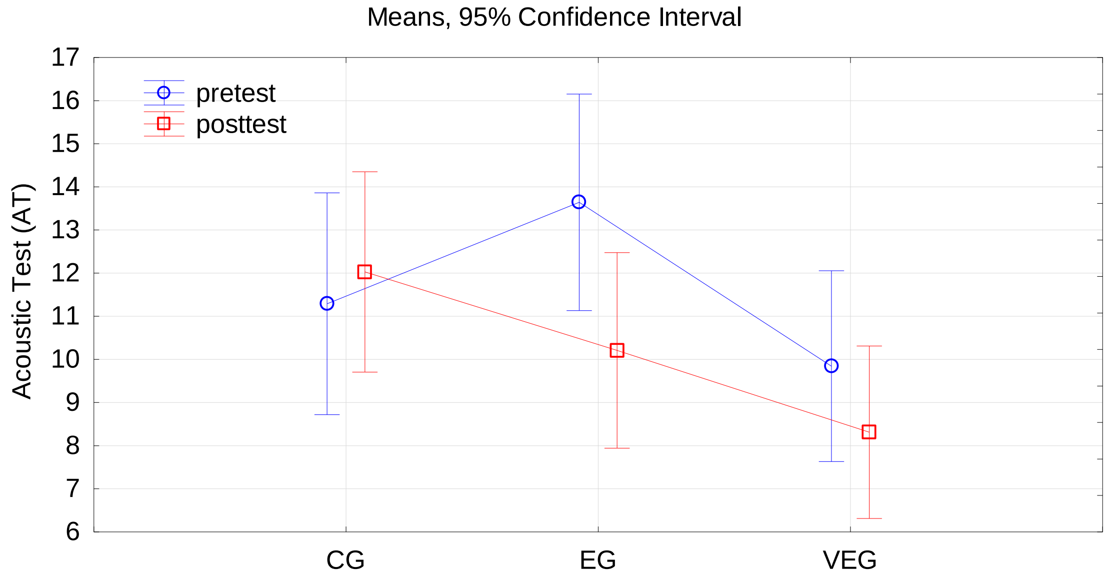

Figure 23: Pre- and posttest results of the Acoustic Test in CG, EG and VEG

4.1.6. Results of the Sensitivity Test (ST)

The sensitivity test as a method for evaluation of the sense of touch and proprioception shows the following results.

At the pretest there were differences between the EG and the CG. The participants of the CG identified most of the identical test pairs while the members of the EG found the fewest pairs (see Table 1 and Fig. 24).

Each group improved at the posttest after the 10 weeks intervention compared to the pretest, but only significant changes appeared in the EG and the VEG.

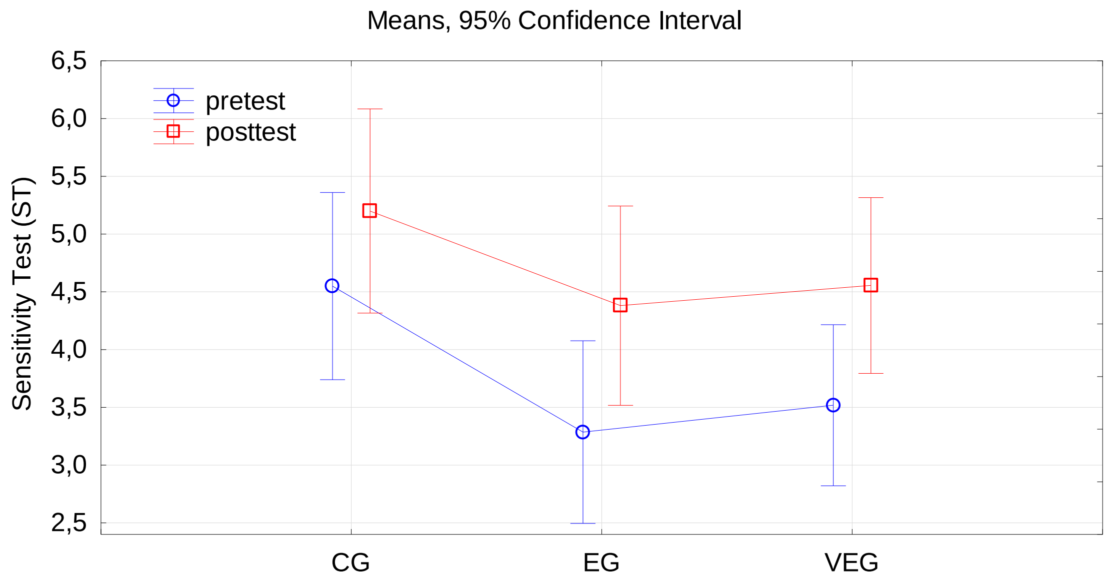

Figure 24: Pre- and posttest results of the Sensitivity Test in CG, EG and VEG

4.2. Analysis of correlations occurring between the level of cognitive functions in different groups of project participants (pretest vs posttest)

To describe the linear correlation of the individual variables within the test groups, the Spearman correlation test was applied. Most of the correlations were found between the variables of the d2-R test among each other, as they are partially interconnected and interdependent in the design of the test. Therefore, the correlations of the variables from the other tests, both in relation to the variables of the d2-R test and to each other, were specifically considered and included in the description of the test results.

4.2.1. Relationships between the variables of the d2-R test

As mentioned above, strong correlations exist between several variables of the d2-R test, which are due to the test design. The variables named „Test processing speed (PTO), „Omission Errors“ (OE) „Confusion Errors“ (CE) „Concentration Performance“ (CP) and „Diligence in test processing“ (E%) are each assigned to the d2-R test and among them the most correlations can be found (see Tables 4, 5 and 6).

There are very strong positive correlations in all groups as well in the pretest as well in the posttest between the variables for PTO and CP. Similarly, very strong positive correlations between the variables for OE and E% with values for r = 0,83 to r = 0,97 are shown in all groups at pretest and posttest.

Strong negative correlations occurred in each case for EG and VEG in both the pre-test and posttest between the OE and CP.

The number of occurrences of strong correlations in the individual groups concerning the variables of the d2-R test is remarkable: in the pretest 2 strong correlations in the CG, 4 in the EG and 7 in the VEG, in the posttest 3 in the CG, 5 in the EG and 6 in the VEG.

4.2.2. Relationships between d2-R test variables and verbal fluency, verbal and numeric memory, acoustic and sensitivity test

At the pretest of the CG there were strong positive correlations between numeric test variables and CE and numeric test variables and diligence in test processing (see Table 4). Likewise a moderately strong positive correlation between the variables verbal fluency and the word memory test was found in this group. The variables of the sensitivity test and the OE also correlate moderately strong positively in the pretest of the CG.

Correlation Pretest

Table 4: Spearman's correlation pretest, Control group. Coefficients statistically significant at the $p < 0,05$ level are shown in bold font

Variable	Test processing speed (PTO)	Omission Errors (OE)	Confusion Errors (CE)	Concentration Performance (CP)	Diligence in test processing (E%)	Numeric memory test (DSRN)	Verbal memory test (IFRW)	Verbal fluency (COWAT)	Acoustic Test (AT)	Sensitivity Test (ST)
Test processing speed (PTO)	--	-0,10	0,38	**0,94**	0,03	-0,18	0,35	0,32	-0,15	-0,24
Omission Errors (OE)	-0,10	--	-0,07	-0,28	**0,83**	0,32	0,08	0,06	-0,02	**0,62**
Confusion Errors (CE)	0,38	-0,07	--	0,20	0,38	**0,45**	-0,01	-0,09	-0,03	-0,03
Concentration Performance (CP)	**0,94**	-0,28	0,20	--	-0,19	-0,28	0,29	0,36	-0,20	-0,36
Diligence in test processing (E%)	0,03	**0,83**	0,38	-0,19	--	**0,62**	0,24	0,10	-0,11	0,41
Numeric memory test (DSRN)	-0,18	0,32	**0,45**	-0,28	**0,62**	--	-0,02	-0,20	-0,08	-0,06
Verbal memory test (IFRW)	0,35	0,08	-0,01	0,29	0,24	-0,02	--	**0,63**	-0,33	-0,21
Verbal fluency (COWAT)	0,32	0,06	-0,09	0,36	0,10	-0,20	**0,63**	--	-0,28	-0,04
Acoustic Test (AT)	-0,15	-0,02	-0,03	-0,20	-0,11	-0,08	-0,33	-0,28	--	-0,13
Sensitivity Test (ST)	-0,24	**0,62**	-0,03	-0,36	0,41	-0,06	-0,21	-0,04	-0,13	--

At the pretest of the EG, the variables correlated weakly positive between the numeric memory test and the CP and the verbal memory test and the CP, and between verbal memory test and verbal fluency (see Table 5).

In the VEG, the pretest showed a weak positive correlation in the variables of verbal fluency and test processing speed (PTO) and a weak negative correlation between the variables of the sensitivity test versus confusion errors (CE) (see Table 6).

At the posttest, except correlations of the variables of the d2-R test, only one moderately strong negative correlation between the variables of the numeric memory test and the sensitivity test was detected (see Table 7).

Also in the EC, apart from the correlations between the variables of the d2-R test, there was only one weak positive correlation between the variables of verbal fluency and test processing speed (see Table 8).

No significant positive or negative correlation except between the variables of the d2-R test occurred in the posttest of the VEG group.

Table 5: Spearman's correlation pretest, Exercise group. Coefficients statistically significant at the p < 0,05 level are shown in bold font

Variable	Test processing speed (PTO)	Omission Errors (OE)	Confusion Errors (CE)	Concentration Performance (CP)	Diligence in test processing (E%)	Numeric memory test (DSRN)	Verbal memory test (IFRW)	Verbal fluency (COWAT)	Acoustic Test (AT)	Sensitivity Test (ST)
Test processing speed (PTO)	--	-0,16	0,05	**0,77**	-0,33	0,42	0,36	0,41	0,19	-0,03
Omission Errors (OE)	-0,16	--	0,20	**-0,59**	**0,93**	-0,18	-0,05	0,13	-0,11	0,30
Confusion Errors (CE)	0,05	0,20	--	-0,29	0,38	-0,07	-0,20	-0,11	-0,10	0,14
Concentration Performance (CP)	**0,77**	**-0,59**	-0,29	--	**-0,74**	**0,46**	**0,44**	0,34	0,19	-0,13
Diligence in test processing (E%)	-0,33	**0,93**	0,38	**-0,74**	--	-0,27	-0,20	-0,06	-0,15	0,27
Numeric memory test (DSRN)	0,42	-0,18	-0,07	**0,46**	-0,27	--	0,31	0,39	-0,28	-0,11
Verbal memory test (IFRW)	0,36	-0,05	-0,20	**0,44**	-0,20	0,31	--	**0,51**	0,00	-0,28
Verbal fluency (COWAT)	0,41	0,13	-0,11	0,34	-0,06	0,39	**0,51**	--	0,06	0,13
Acoustic Test (AT)	0,19	-0,11	-0,10	0,19	-0,15	-0,28	0,00	0,06	--	-0,20
Sensitivity Test (ST)	-0,03	0,30	0,14	-0,13	0,27	-0,11	-0,28	0,13	-0,20	--

Table 6: Spearman's correlation pretest, Vibration group. Coefficients statistically significant at the $p < 0,05$ level are shown in bold font

Variable	Test processing speed (PTO)	Omission Errors (OE)	Confusion Errors (CE)	Concentration Performance (CP)	Diligence in test processing (E%)	Numeric memory test (DSRN)	Verbal memory test (IFRW)	Verbal fluency (COWAT)	Acoustic Test (AT)	Sensitivity Test (ST)
Test processing speed (PTO)	--	-0,30	-0,03	**0,82**	**-0,40**	0,35	0,29	**0,44**	0,05	0,10
Omission Errors (OE)	-0,30	--	**0,43**	**-0,70**	**0,97**	-0,20	0,02	-0,09	-0,16	-0,16
Confusion Errors (CE)	-0,03	**0,43**	--	-0,34	**0,50**	0,28	-0,23	0,10	-0,03	**-0,50**
Concentration Performance (CP)	**0,82**	**-0,70**	-0,34	--	**-0,78**	0,33	0,23	0,31	0,10	0,24
Diligence in test processing (E%)	**-0,40**	**0,97**	**0,50**	**-0,78**	--	-0,15	0,00	-0,04	-0,11	-0,22
Numeric memory test (DSRN)	0,35	-0,20	0,28	0,33	-0,15	--	0,20	0,34	-0,27	-0,16
Verbal memory test (IFRW)	0,29	0,02	-0,23	0,23	0,00	0,20	--	0,34	-0,25	-0,01
Verbal fluency (COWAT)	**0,44**	-0,09	0,10	0,31	-0,04	0,34	0,34	--	0,18	-0,02
Acoustic Test (AT)	0,05	-0,16	-0,03	0,10	-0,11	-0,27	-0,25	0,18	--	0,14
Sensitivity Test (ST)	0,10	-0,16	**-0,50**	0,24	-0,22	-0,16	-0,01	-0,02	0,14	--

Table 7: Spearman's correlation posttest, Control group. Coefficients statistically significant at the $p < 0,05$ level are shown in bold font

Variable	Test processing speed (PTO)	Omission Errors (OE)	Confusion Errors (CE)	Concentration Performance (CP)	Diligence in test processing (E%)	Numeric memory test (DSRN)	Verbal memory test (IFRW)	Verbal fluency (COWAT)	Acoustic Test (AT)	Sensitivity Test (ST)
Test processing speed (PTO)	--	-0,16	0,49	**0,90**	-0,27	0,06	-0,46	0,07	0,05	0,01
Omission Errors (OE)	-0,16	--	0,04	-0,43	**0,86**	0,13	-0,14	-0,05	-0,33	0,03
Confusion Errors (CE)	0,49	0,04	--	0,25	0,27	0,22	-0,37	0,01	-0,15	-0,07
Concentration Performance (CP)	**0,90**	-0,43	0,25	--	**-0,56**	0,00	-0,24	0,03	0,17	0,02
Diligence in test processing (E%)	-0,27	**0,86**	0,27	**-0,56**	--	0,29	-0,26	-0,05	-0,41	-0,11
Numeric memory test (DSRN)	0,06	0,13	0,22	0,00	0,29	--	-0,22	-0,07	-0,36	**-0,64**
Verbal memory test (IFRW)	-0,46	-0,14	-0,37	-0,24	-0,26	-0,22	--	0,15	0,30	-0,01
Verbal fluency (COWAT)	0,07	-0,05	0,01	0,03	-0,05	-0,07	0,15	--	0,07	0,37
Acoustic Test (AT)	0,05	-0,33	-0,15	0,17	-0,41	-0,36	0,30	0,07	--	-0,08
Sensitivity Test (ST)	0,01	0,03	-0,07	0,02	-0,11	**-0,64**	-0,01	0,37	-0,08	--

Table 8: Spearman's correlation posttest, Exercise group. Coefficients statistically significant at the $p < 0,05$ level are shown in bold font

Variable	Test processing speed (PTO)	Omission Errors (OE)	Confusion Errors (CE)	Concentration Performance (CP)	Diligence in test processing (E%)	Numeric memory test (DSRN)	Verbal memory test (IFRW)	Verbal fluency (COWAT)	Acoustic Test (AT)	Sensitivity Test (ST)
Test processing speed (PTO)	--	-0,39	-0,25	**0,94**	**-0,58**	0,32	0,39	**0,44**	0,01	0,09
Omission Errors (OE)	-0,39	--	0,26	**-0,61**	**0,93**	-0,29	-0,07	0,03	-0,06	-0,35
Confusion Errors (CE)	-0,25	0,26	--	-0,36	0,41	-0,02	-0,18	-0,05	-0,28	-0,08
Concentration Performance (CP)	**0,94**	**-0,61**	-0,36	--	**-0,78**	0,38	0,37	0,40	0,02	0,28
Diligence in test processing (E%)	**-0,58**	**0,93**	0,41	**-0,78**	--	-0,34	-0,19	-0,19	0,00	-0,41
Numeric memory test (DSRN)	0,32	-0,29	-0,02	0,38	-0,34	--	0,13	0,36	-0,12	-0,08
Verbal memory test (IFRW)	0,39	-0,07	-0,18	0,37	-0,19	0,13	--	0,33	-0,33	0,21
Verbal fluency (COWAT)	**0,44**	0,03	-0,05	0,40	-0,19	0,36	0,33	--	-0,31	0,43
Acoustic Test (AT)	0,01	-0,06	-0,28	0,02	0,00	-0,12	-0,33	-0,31	--	-0,11
Sensitivity Test (ST)	0,09	-0,35	-0,08	0,28	-0,41	-0,08	0,21	0,43	-0,11	--

Table 9: Spearman's correlation posttest, Vibration group. Coefficients statistically significant at the $p < 0,05$ level are shown in bold font

Variable	Test processing speed (PTO)	Omission Errors (OE)	Confusion Errors (CE)	Concentration Performance (CP)	Diligence in test processing (E%)	Numeric memory test (DSRN)	Verbal memory test (IFRW)	Verbal fluency (COWAT)	Acoustic Test (AT)	Sensitivity Test (ST)
Test processing speed (PTO)	--	-0,22	**0,51**	**0,91**	-0,26	0,19	0,09	0,31	-0,23	0,20
Omission Errors (OE)	-0,22	--	0,06	**-0,53**	**0,95**	-0,12	0,03	-0,23	0,23	-0,07
Confusion Errors (CE)	**0,51**	0,06	--	**0,41**	0,21	0,31	0,19	0,23	0,10	0,24
Concentration Performance (CP)	**0,91**	**-0,53**	**0,41**	--	**-0,57**	0,24	0,16	0,26	-0,25	0,24
Diligence in test processing (E%)	-0,26	**0,95**	0,21	**-0,57**	--	-0,13	-0,05	-0,21	0,29	-0,04
Numeric memory test (DSRN)	0,19	-0,12	0,31	0,24	-0,13	--	0,33	0,21	0,18	-0,21
Verbal memory test (IFRW)	0,09	0,03	0,19	0,16	-0,05	0,33	--	0,27	0,01	0,37
Verbal fluency (COWAT)	0,31	-0,23	0,23	0,26	-0,21	0,21	0,27	--	-0,07	0,27
Acoustic Test (AT)	-0,23	0,23	0,10	-0,25	0,29	0,18	0,01	-0,07	--	-0,04
Sensitivity Test (ST)	0,20	-0,07	0,24	0,24	-0,04	-0,21	0,37	0,27	-0,04	--

Due to the fact of the large number of variables taken into account, as well as because the analysis of individual relationships in the three groups in the pre- versus post-study may cause a certain problem in the following part of the dissertation, a summary of the observed relationships was made.

It can be seen that in comparison from the pretest to the posttest, the total number of significant correlations decreased as well as in the 3 groups added (CG + EG + VEG) as well as in each group separately (see Table 10). That means that correlation between variables except between the variables of the d2-R test were very rare and usually weak.

Looking only at the correlations among the variables of the d2-R test, it is evident that the total number of strong correlations of the 3 groups together increased by one in the posttest compared to the pretest (see Table 11). Considering the groups separately, the number of strong correlations increased by one in each of CG and EG at posttest and decreased by one in VEG at posttest compared to the pretest.

The smallest number of correlations between the variables apart from the d2-R test among themselves were found in the posttest of all groups: the total number (CG + EG + VEG) decreased from 8 in the pretest to only 2 in the posttest (see Table 12). These were distributed as follows: one in the CG, one in the EG, and none in the VEG.

Table 10: Total number of correlations among all the variables

	CG	EG	VEG	Total
pretest	5	7	9	21
posttest	4	6	6	16

Table 11: Number of correlations among the variables of the d2-R test

	CG	EG	VEG	Total
pretest	2	4	7	13
posttest	3	5	6	14

Table 12: Number of correlations between other variables among each other and variables of d2-R test

	CG	EG	VEG	Total
pretest	3	3	2	8
posttest	1	1	0	2

Since significant simple correlations between the variables included in the study were very rare, a regression analysis (stepwise regression method) was conducted. This provided an answer to the question of the set of explanatory variables that are most influential in explaining the results of CP.

4.3. Results of multiple correlation of cognitive functions of study participants (stepwise regression analysis)

As CP is the most important from the point of view of labor efficiency, so it was decided to explain the results of this variable using the results of other variables that are treated as explanatory variables.

Thus, in the following description in the regression analysis, the explained variable is CP, and the explanatory variables are PTO, acoustic, sensitivity, numeric memory and verbal memory.

The d2-R test variables were excluded from the group of explanatory variables for Concentration Performance except for the PTO variable, which was the only variable always and most highly correlated with CP in simple correlations.

The regression analysis was calculated separately for the pre- and posttest results, and then the R^2 multiple correlation coefficients were compared, as well as the type of variables explaining the Concentration Performance results along with the beta coefficient (see Table 13).

At the pretest, the number of processed target objects (PTO) emerged as a significant explanatory variable for explaining CP in each group. In the case of the EG, sensitivity was also considered as being significant in explaining the CP.

Noteworthy here is the R^2 value of the results of the explanatory variables regarding the explained variable CP in the 3 groups in the pretest:

The EG with the highest value of R^2 = 0,85 for the variables PTO and sensitivity, the CG with R^2 = 0,80 for the variable PTO and VEG with the lowest value of R^2 at the pretest with R^2 = 0,59 for the variable PTO.

At the posttest the explanatory variables remained the same as in the pretest (PTO, acoustic, sensitivity, numeric and verbal memory) and also the explained variable CP was the same.

At the posttest the explanatory variable PTO was still obvious of being significant in explaining the CP in each group. Only in the VEG appeared a second significant explanatory variable additionally to the PTO to explain the variable CP: the numeric memory. After the 10-week training intervention the value of R^2 is higher in all groups at the posttest than in the pretest. In the EG the value of R^2 = 0,89, in the CG R^2 = 0,92 and in the VEG R^2 = 0,81.

According to the stepwise regression analysis method the PTO is the most important variable to explain the CP in all tests (pretest and posttest) and in all groups (EG, CG and VEG). One additional variable was found at the pretest (sensitivity) in only one group (EG) and also one additional explanatory variable was found at the posttest (numeric memory) in only one group (VEG).

Table 13: Results of the multiple correlation

Group		PTO		Sensitivity test		Acoustic test		Numeric memory test		Verbal memory test	
		ß	ß st. e.	ß	ß st. e.	ß	ß st. e.	ß	ß st. e.	ß	ß st. e.
CG pretest	CP	0,898	0,113								
	R^2	0,794									
	F, p	62,76	0,0000								
CG posttest	CP	0,964	0,080								
	R^2	0,923									
	F, p	145,69	0,0000								
EG pretest	CP	0,8780	0,093	0,208	0,093						
	R^2	0,839									
	F, p	50,38	0,0000								
EG posttest	CP	0,948	0,073								
	R^2	0,894									
	F, p	170,08	0,0000								
VEG pretest	CP	0,773	0,132								
	R^2	0,580									
	F, p	34,13	0,0000								
VEG posttest	CP	0,793	0,100					0,275	0,100		
	R^2	0,795									
	F, p	43,59	0,0000								

R^2– Square multiple corrected
ß – beta
ß st. e. – beta standard error
CP – concentration performance

A comparison of R^2 values by group in the pre- vs post studies shows that in the VEG group, the results of the CP variable were explained the least by the results of the explanatory variables (see Table 13). Thus, the results of the CP variable were strongly influenced by other variables that were not initially included in the study. However, after the end of the 10-week intervention, the contribution of the cognitive variables included in the study in explaining the CP score in the VEG group increased significantly, which may suggest the indirect stimulatory nature of vibration on these cognitive functions (explanatory variables), mainly for PTO and numeric memory. As shown in Table 14, the R^2 value increased in each group from the pre- to the posttest, but especially remarkably in the VEG.

Table 14: Changes in the R^2 in the group of participants: CG, EG, and VEG (pretest vs posttest)

R^2 multiple corrected	CG	EG	VEG
Pretest	0,794	0,839	0,580
Posttest	0,923	0,894	0,795

5. Discussion

Considering the current situation especially after the COVID 19 pandemic concerning the ascertained decrease of PA in the population and particularly in young people and the associated negative consequences in physical and mental health, the main purpose of this study was to investigate the application of short exercise programs additional to the usual PA program offered through school and leisure activities on cognitive functions in adolescents. In several studies a positive association between moderate PA and the performance of cognitive functions such as concentration, executive functions, memory, etc. has been shown (Hillman et al. 2008; Álvarez-Bueno et al. 2017; Donelly et al. 2016). Even before the worldwide COVID 19 pandemic the *World Health Organization 2020 Guidelines on Physical Activity and Sedentary Behavior* reported that more than three quarters of the adolescents did not meet the recommendation of the WHO of 60 minutes of PA per day. The fact that more and more children and adolescents spend their time sedentarily can lead to health consequences in the long term. Not only physical parameters such as overweight and obesity, cardiovascular problems, blood pressure issues, quality of sleep etc. are related to the lack of PA, also mental performance and brain health are linked to a sufficient amount of PA.

As described in the introduction, global efforts to contain the spread of COVID 19 have further exacerbated this tendency. School closures, playground and sports facility closures, social distancing, distance learning etc. led to isolation of school-aged children and adolescents and to reduced interaction and PA (Schmidt et al. 2020; Viner et al. 2022). During school closures, classes were held online, which in turn increased sedentary time and exposure to screens.

The consequences of a sedentary lifestyle and increasing exposure to screens can create severe health concerns in the physical, psychological and mental well-being in our society in the future. As for adolescents it is of major importance for the academic achievement and the future working performance, the focus of this research has been on the investigation of the effects of particular exercise programs on cognitive functions. Labor efficiency, which is characterized by concentration performance, accuracy, speed of working processes, verbal expression, numerical comprehension etc. is an important criterion for the future position in working and social life of young people. Therefore, it is of prior necessity to promote programs and activities especially for the young population which enhance the cognitive performance. This research project was planned before COVID 19 and now seems to be of even greater interest as decrease of PA and increase of sedentary and screen time was noticed especially during this period of time. The lack of PA and the psychological consequences of the pandemic measures, such as anxiety and depression, also affect cognitive performance and mental health of adolescents (Menze et al. 2022).

5.1. Stimulation and cognitive functions

Brain areas develop according to use and stimulation. In the approach of Embodied Cognition, the human body and its interaction with the environment plays a significant role in cognition (Watson et al, 2014; Dove, 2015) The brain is not understood as an isolated organ responsible for cognitive processes, but as a system of interaction between the brain, body and environment in which perception and action are of key importance. The activation of the body and the nervous system by appropriate stimuli entail an activation of the brain. The motions of an organism create a permanently changing pattern of stimulation which supports cognitive functions such as learning, understanding and memorizing (Shapiro and Spaulding, 2021). Areas and brain structures which are involved in the body-related activities build neuronal networks which represent and store the information (Hebb, 1949).

In this view cognition and cognitive functioning is based on sensory and motor experiences (Mahon and Hickok, 2016) which create sensory-motor representations in the brain (Barsalou, 2008). As well as sensory-motor experiences influence our nervous system, neuronal networks and cognition, further signals coming from other parts of the body (e.g. ears, eyes, mouth, nose) with their stimuli are also interconnected with the human brain and form the mind and cognition (Macedonia, 2019). So cognitive functions are related to the activation of the body and can be promoted by the targeted use of stimuli.

Considering the well-known effects of PA for mental health and cognitive functions in general and the approach of Embodied Cognition with the integration of the brain as a part of the sensory-motor and perception system interconnected with a number of neuronal networks, the significance of physical exercise and the stimulation of the nervous system in different ways to enhance cognitive performance is obvious.

PA stimulates the brain via proprioceptive stimuli and neuromuscular connections. The movement is planned in the frontal lobes of the brain and is carried out by signals emitted by the efferent nerve pathways to the innervated muscles. In return, the muscles communicate through proprioceptive signals (muscle length, joint position, muscle tension) via afferent nerve pathways with the brain. This neural communication activates the appropriate areas of the brain.

Additional stimuli create further action potentials (when the threshold is reached), which are sent through the nervous system as an electrical impulse and subsequently form synapses (nerve cell connections) that communicate via chemical neurotransmitters with other neurons. In this way, neuronal networks are built in relationship to the action and perception of the body through different stimuli.

The VGD produces stochastic vibratory signals that by their characterization are not predictable and create more action potentials than vibration with a sinus wave (Haas et al. 2005). When more neuronal impulses are transmitted through the nervous system, more synapses are formed between neurons and thus entire neuronal networks. The typical vibration of the VGD is an essential component for the increased creation of action potentials. The more the neurons fire the more synapses and neuronal networks are built.

These considerations were at the beginning of the research to examine the effects of additional PA, additional PA with a device (VGD), and no additional activity for the participants of the study.

The device (VGD) has already been described in chapter 3.2. (Study Procedure) concerning the physical parameters and the kind of vibration produced. Further stimuli are created while swinging or moving the VGD:

- sense of touch by holding the handles of the swing-ring-system tight in the palms of the hands,
- visual stimuli by the object itself (color, shape, size),
- acoustic stimuli by the noise of the steel balls inside rolling from one end to the other by swinging it,
- weight and gravity displacements due to centrifugal force when moving the VGD (graviceptors).

It has to be noted that the whole range of stimulation of the VGD is applied when using it and not only the local stochastic vibration. With the VGD it is not possible to separate the effect of vibration from the others and to isolate it. Once the VGD is used for exercises, the brain receives this additional information through the nervous system.

The body-brain-mind entity from the point of view of the Embodied Cognition develops through stimulative interaction of the body with the environment (Craighero, 2022). In natural environments, people are exposed to a wide variety of stimuli, whereas in indoor environments such as school buildings, they only come in contact with a reduced selection of stimuli, e.g. walking across a natural forest floor provides much more neural information than walking across a flat floor in a building. In most schools, learning traditionally takes place in classrooms in sitting position, usually while listening and writing down what is explained by the teacher using the blackboard, projections, books or other tools. Moving and learning in natural environments with rich stimulation to influence cognitive functions is not common and not practical in our school systems.

Vibration is a stimulus that is met very often in everyday life: With every step, vibrations are generated when the foot touches down on the ground and are transmitted by the nervous system. Humans get in contact with vibrations by taking the bus or the car, by using electrical devices such as toothbrushes or blenders, by going by bike (especially mountain biking), by riding and other sports, by hearing music near a loudspeaker and even by speaking or singing. On the one hand side there are natural vibrations created by humans (in interaction with the environment) and on the other side there are device generated vibrations to which humans are exposed.

The vibratory receptors (Meissner and Pacinian corpuscles) are well developed in humans and cover a wide range of frequencies (Harada, 1991; Oroszi, 2020). The conducting nerve fibers are of the Aβ II type with a myelinated outer layer, which ensures rapid transmission of the stimulus, only Aα nerve fibers are faster in transmitting proprioceptive stimuli (Baer et al. 2009). This means that vibratory signals are transmitted faster to our sensory cortex than e.g. signals of temperature or pain and are then processed there.

To summarize, vibration is thus a stimulus that occurs frequently in everyday life and is well received and quickly transmitted by the human sense of vibration. For this research vibration was added to the PA program using VGD based on these conditions. School environments are often low in stimuli and therefore it seemed interesting to use an additional device for the PA program, that generates a variety of stimuli, such as local stochastic vibration, visual, haptic, acoustic and gravity stimuli.

5.2. Results on selected cognitive functions

With the use of commonly known tests a wide range of selected cognitive functions has been assessed: the general concentration performance, composed of processing speed, accuracy and error-percentage, verbal fluency, verbal and numeric memory, directional hearing and proprioception and sense of touch.

When setting up the research, it was expected that the results of the participants of the 3 groups (CG, EG, VEG) would develop differently according to the additional PA programs. It was hypothesized that the outcomes of the tests assessing selected cognitive functions of the group that received additional PA and stimuli of the VGD (VEG) would improve the most, followed by the results of the exercise group (EG) and then the control group (CG) that received no additional exercise program.

Regarding the results of the Least Significance Differences (LSD) test, it is remarkable, that there are the following significant changes from the pretest vs posttest for the total of 12 variables examined in the 3 groups:

Table 15: LSD test, number and type of significant differences within the 3 groups at the pre- vs posttest

Group	Number of significant differences pre- vs posttest	Variables with significant differences
CG	4	Test processing speed (PTO), Concentration Performance (CP), Standard values PTO, Verbal memory (IFRW)
EG	7	Test processing speed (PTO), Concentration Performance (CP), Standard values PTO, Verbal fluency (COWAT), verbal memory (IFRW), Acoustic Test (AT), Sensitivity Test (ST)
VEG	9	Test processing speed (PTO), Omission Errors (OE), Concentration Performance (CP), Diligence in task processing (E%), Standard values PTO, Standard value E% Verbal fluency (COWAT), Verbal memory (IFRW), Sensitivity Test (ST)

Within the individual groups, the results of 9 from 12 variables improved statistically significantly in the VEG, 7 from 12 variables changed significantly in the EG and 4 from 12 in the CG, that means most of the significant differences in the results occurred in the VEG from the pre- vs posttest, followed by the EG and then the CG.

The intergroup comparison supports the hypothesis that most significant changes occurred in the group with additional PA program and VGD. The intragroup comparison (pre- vs posttest) supports the hypothesis that most significant changes occurred in the group with additional PA program and VGD, then the EG and at least the CG. It is noteworthy, that only in the VEG the results of the variables of omission errors (OE) and Diligence in task processing (E%) improved significantly and the results of the acoustic test only in the EG.

It seems as if the additional stimulation of the VGD during the PA program helped to reduce errors, especially omission errors which means that the participants recognized and marked more of the right objects.

In the intragroup comparison the VGD seems not to have a significant impact on acoustic perception and proprioception, but simple PA program does. This is rather surprising, because the noise of the VGD stimulates the auditory system and vibration is known to have an impact on the proprioception (Pollock et al. 2011). To have an explanation for this phenomenon it is surely useful to consider the intergroup comparison of the acoustic variable. There it can be seen that there is a significant difference in the results of the pretest between the EG and the VEG. The mean value of the measured distance from the noise source in the EG is about 14 cm and about 10 in the VEG in the pretest whereas at the posttest the mean value in the EG is about 10 cm and in the VEG about 8 cm (see Fig. 22). One possible explanation for this result is that the EG started with a result much farther from the noise source than the VEG, and significant improvement in terms of approaching the noise source was easier to achieve than in the VEG. It should be noted that the value of EG at posttest is approximately equal to the value of VEG at pretest and that the results of the VEG are closest to the noise source at the posttests of all 3 groups.

All 3 groups have statistically significant differences in intragroup comparison regarding the pretest vs posttest in the variables of PTO, CP, Standard value PTO and IFRW. As the standard value PTO is directly related to the value of PTO in the same age group (15- and 16-year-old participants) with the same coefficient it will neglected in the following analysis. In the detailed consideration of the results between the 3 groups in the pretest and posttest, approximately similar representations of the results appear.

The results of the mentioned variables of the pretest in the EG are always at the lowest level compared to the results of the pretest of the CG and the VEG. The results of the CG and VEG are at a similar level at the pretests of these 3 variables. At the posttest the results of the participants of the VEG reach in all variables the highest level compared to the other groups with significant differences in comparison to the EG concerning PTO and CP and in comparison to the CG concerning COWAT (see Fig. 10, 13, 20).

The CP is one of the most important variables, which is the number of PTO minus the errors (OE and CE). In the results, information about both the speed and the accuracy of the test processing can be seen in the total number. CP was significantly improved in intragroup comparison pretest vs posttest through the gain of speed in test processing (higher number of PTO) and in the VEG also through less OE. Accuracy seems to be affected especially by the PA with VEG.

The same conclusion becomes evident when considering the results of the working style of the 3 groups in intragroup comparison. All 3 groups improved significantly from the pre- vs posttest concerning working speed (standard value PTO) but only VEG improved significantly concerning diligence in test processing (standard value E%) (Fig. 15 and 16).

Regarding the working style in test processing, results of the participants of the 10-week intervention program were expected to be found in the 4th quadrant (fast and accurate) (see Fig. 17). As intended the results of the participants VEG gained the most percent at pre- vs posttest in the 4th quadrant (26%), whereas surprisingly, the results of the participants CG come in the 2nd place and only in the 3rd place EG.

Another remarkable result is that in the first quadrant in the posttest only results of the participants of the EG can be found, all other results of the VEG and CG are entered in other quadrants (Fig. 18). The most important increase in quadrants 2 and 3 is provided by the VEG at pre- vs posttest (Fig. 19).

Concerning the results of the working style in test processing this is not exactly what was expected. The results of the subjects of the VEG behaved as expected and showed the largest increase in percentage of results in the 4th quadrant and also in quadrant 2 and 3 in the pre- vs posttest (compared to the CG and EG), clearing all results in the first quadrant. In contrast, the results of the participants of the EG show the least percentage improvement in quadrant 4, 2 and 3, even results of members of this group remained as the only one in the first quadrant at the posttest. This means that the results of the subjects of the CG on this variable represent a higher score in the working style than the EG although no additional PA was carried out.

A possible explanation for this is the duration of the intervention program. Haapala (2012) found out that short intervention programs under 34 or 64 weeks had little or no effect on cognitive functions or academic performance. It seems that the exercise program with the additional use of VGD, even applied over a short period of time, may intensify the effects of PA on cognitive functions, namely working style in test processing (speed and accuracy).

The results of the participants of the sensitivity test (ST) show a significant increase in the comparison between the pre- and the posttest within the members of EG and the VEG. This suggests that the sense of touch responds almost equally to PA or PA with use of VGD even after a 10-week intervention program. In the results of the participants of CG no significant differences were noted at the pre- vs the posttest which corresponds to the suspected outcomes.

The analysis of correlations between the variables which were not dependent from each other was not very meaningful as strong correlations were very rare (see Table 12). As no regularity in the correlation of the variables outside the d2-R test could be found the analysis of stepwise regression was considered explaining the expected results of the explained variable of CP through the mentioned explanatory variables. Only the R^2 value of PTO seems to explain most the variable of CP in all groups in all tests (pre- and posttest). As there is an important increase in the R^2 value of the VEG from the pre-vs the posttest to explain CP there have to be other variables which may be very important for understanding the relationships of the explanatory variables with the CP which were not investigated in this research.

PA and vibration especially in the context of the used VGD affect the organism, the nervous system and the brain in a complex way. To understand more of the mutual influences of PA and PA with VGD on the body and especially cognitive functioning further studies have to be conducted among young people without health issues. It would be necessary to investigate and find further variables which influence most the positive effects on cognitive function through use of VGD.

The original intention of this study was to collect results that would go along way toward clarifying the role of vibration in stimulating cognitive functions in school-aged students. This task has been accomplished to a considerable extent. However, a critical analysis of the results obtained allows us to note some limitations worth taking into account in the planning of future studies.

As shown in the flowchart (Fig. 9) the number of participants in the different groups was not constant from the beginning to end of the study and decreased from the pretest to the posttest differently in each of the groups (CG, EG and VEG). With a larger number of test results in the pre- and posttest, more reliable evaluations could be effectuated.

Stimuli of VGD cannot be isolated, especially from the point of view of stochastic vibration. The whole range of stimuli is acting together and that seems to evoke complex reactions. It is not possible to isolate the vibratory stimulus so results of the research concerning the members of the VEG with PA and additional use of VGD are always representing additional PA including all stimuli of VGD.

The duration of the research project with a 10-week intervention program for obtaining results in cognitive functioning is set at the lower limit. A longer duration could have been providing different and perhaps more meaningful results especially in explaining correlations of the variables and the explanatory variables to understand the explained variable of CP.

As there is no equal or similar study investigating the effects of additional PA with use of VGD on cognitive functions of adolescents it is not evident to place the results in the context of existing examinations. There are many studies and systematic reviews examining the relationship of PA and cognitive functioning in children and adolescents, but none using vibration or VGD.

The situation is similar with studies on vibration: although studies have been conducted with adults or older people suffering from different health issues especially in the musculoskeletal or nervous system showing positive effects (Zurek et al. 2022; Musumeci, 2017; Haas et al. 2005; Awan et al. 2017; Saggini et al. 2016) but none has been conducted with young and healthy people investigating the use of vibration in relation to cognitive functions.

PA and vibration especially in the context of the used VGD affect the organism, the nervous system and the brain in a complex way. To understand more of the mutual influences of PA and PA with VGD on the body and especially cognitive functioning further studies have to be conducted among young people without health issues. It would be necessary to investigate and find further variables which influence most the positive effects on cognitive function through use of VGD. The results of some variables of the selected cognitive functions of the participants in the three groups (CG, EG, VEG) already differ significantly in the pretest. This could be taken into account in future studies and possibly mitigated by larger groups or other inclusion criteria, which would allow a clearer evaluation of the results. Increasing the number of test subjects would also lead to more results that can be evaluated in relation to dropouts of participants during the course of the research project.

Conclusion

This research aimed to identify the results of application of local stochastic vibration concerning selected cognitive functions in adolescents through execution of an additional 10-week intervention program. In order to receive clear answers to the research questions, 3 different groups of study participants at the age of 15 and 16 years were created, whose test results could be compared, evaluated and interpreted before and after the 10-week program: the Control Group (CG) without any additional PA program, the Exercise Group (EG) with an additional 25 minute PA program twice a week with moderate exercises and the Vibration Exercise Group (VEG) with an additional 25 minute PA program with VGD twice a week with moderate exercises.

The first research question seeks to answer whether there is a difference in the level of cognitive functions of students who participated in the 10-week intervention program (EG and VEG) compared to those who did not participate in an additional PA program and if so, what is the difference?

Considering Tables one and 15 it becomes evident that there is a remarkable difference in the number of statistically significant changes of the assessed variables comparing the results of the participants of CG to EG and CG to VEG. The results of the participants of the CG reached a significant improvement from the pre- to the posttest after 10 weeks only in 4 variables: PTO, CP, Standard values of PTO and IFRW, whereas the results of the participants of the EG improved significantly in 7 variables: PTO, CP, Standard value PTO, COWAT, IFRW, AT and ST and results of the participants of the VEG after the 10-week intervention program in 9 variables: PTO, OE, CP, Standard value PTO, Standard value E%, IFRW, AT, ST.

The variables are related to cognitive functions and provide the following information:

- PTO: speed in test processing,
- CP: Concentration Performance (speed and accuracy),
- Standard values of PTO: standardized and listed PTO value depending on age group and result to make it comparable to other age groups,
- IFRW: verbal memory,
- COWAT: verbal fluency,
- AT: directional hearing and proprioception,
- ST: sense of touch,

— OE: concentration on marking the right test objects,
— E%: accuracy of test proceeding,
— Standard value E%: standardized and listed E% value depending on age group and result to make it comparable to other age groups.

Results of the participants of EG and VEG improved significantly in more variables related to selected cognitive functions than in CG after the 10-week intervention program. Therefore it can be concluded, that the additional PA program seems to achieve effects on test scores of the before shown cognitive functions in adolescents.

The second research question aims to find an answer whether it makes a difference in terms of the level of cognitive functions of adolescents whether the PA was performed with or without VGD (results of participants of EG compared to VEG) for the 10-week intervention program.

Little difference could be found in the number of statistically significantly improved results of the participants of the EG and the VEG: the LSD test shows a number of 7 variables related to selected cognitive functions in the results of the members of EG compared to 9 in the group of the VEG after the appropriate 10-week intervention program (see Tables one and 15). Additional PA with stimulation through VGD seems to affect more cognitive functions than only PA during a period of 10 weeks.

The third research question seeks to answer whether participation in a 10-week intervention program with or without VGD makes a difference in changes in cognitive functions, and if so, which functions are affected and the nature of the changes.

There is evidence that the additional use of VGD during 10 weeks intervention program favors the improvement of the results in the VEG compared to the EG. Concerning the working style, which represents the two functions of working speed in test processing and accuracy or diligence in test processing together, the results of the members of the VEG reached most of the improvements in all quadrants in percentage compared the pre- to the posttest. The results of the members of the EG improved the least in percentage terms and are even lower compared the results of the improvements in percentage of the CG. In relation to the results of the working styles of test processing, results of participants of the VEG showed improvements not only in test processing speed (as did also the results of the members of CG and EG) but especially in the accuracy of test processing were made. This change is most apparent and only concerns the results of the subjects of VEG during the period of the project.

There were different cognitive functions explaining CP results in the different participating groups. In all groups, both pretest and posttest results showed that higher test speed processing (PTO) was associated with higher CP. Participation in a 10-week intervention program may primarily result in higher CP through better accuracy in reducing errors.

It has also been shown that in all groups and at both tests results of the variable for test processing speed explained CP whereas in the EG at the pretest additionally the variable for the ST and in the VEG at the posttest additionally the variable for the numeric test explained the CP. It remains to be further investigated to what extent the influence of numerical memory in VEG results explain CP. It has to be considered that little improvements in the test processing speed can also be due to a certain extent to a training effect by repeating the same or similar tasks at the posttest.

The results of this study allow the conclusion that both, the additional PA and PA with VGD, in a 10-week intervention program affect a big number of the assessed selected cognitive functions in adolescents. However, the PA with VGD seems to be much more effective than PA without VGD and that additional stimulation with the effects of VGD during PA has an obvious impact on error reduction and thus improvement in accuracy.

The program with VGD in moderate intensity could be advantageous for receiving more improvements in cognitive functions within a relatively short time. This seems to be promising results which should be investigated more intensively to know more about the effect of vibration on cognitive functions.

This is of particular importance during and after the COVID 19 pandemic due to the fact that short, moderate, effective and attractive PA programs have high potential to counteract the effects of the crisis on mental health and cognitive functions in adolescents and focus on the accuracy and working style of task processing.

Abstract

In the context of an increasingly sedentary society, in which children and adolescents, in particular, do not achieve the physical activity goals set by the WHO 2010 guidelines of at least 60 minutes a day by more than 80% (Bull et al. 2020), and especially after the aggravated situation during and after the COVID 19 pandemic, this Ph.D. dissertation investigates the effectivity of short and moderate exercise programs with and without a vibration generating device (VGD) when carried out regularly for 10 weeks as part of the school lessons in adolescent students additionally to the usual PA program in school and leisure time and shows the results concerning selected cognitive functions.

The research aim was to find out whether there were differences in the outcome after a 10-week intervention program in the 3 different groups concerning the level and the changes in selected cognitive functions.

In the form of a pre- and posttest study, 15- and 16-year-old students participated in 3 groups: the Control Group (CG) with no additional PA, the Exercise Group (EG) with additional PA without VGD, and the Vibration Exercise Group (VEG) with additional PA and use of VGD. Selected cognitive functions were assessed with commonly used tests for attention, speed of processing tasks, concentration performance, accuracy, verbal fluency, verbal memory, numeric memory, etc.

Data was collected and analyzed by showing significant differences in independent samples, correlations, and explanatory variables for the Concentration Performance (CP) being one of the most important variables.

Results show that most of the statistically significant improvements of the variables for cognitive functions occur in the VEG, followed by the EG and at least CG after the 10-week intervention program. The improvement of the working style in percentage behaves as follows: most improvement in all sectors for the results of participants of VEG, followed by CG and at least EG which is rather surprising and possibly due to the short duration of the intervention (Haapala, 2012). CP is mainly related to PTO (working speed) and some further variables especially in EG and VEG.

There is evidence that PA with VGD may affect more cognitive functions in adolescents in a relatively short period of time of 10 weeks than PA without VGD and high potential for enhancing CP by improving accuracy in reducing errors. Further investigation with a larger number of study participants and examination of the application of local stochastic vibration on additional variables related to cognitive functions in adolescents are needed to better understand the effects of PA with additional use of vibration on cognitive functions.

Streszczenie

Nasilające się zachowania sedenteryjne społeczeństwa, obserwowane na przestrzeni kolejnych lat, a w szczególności sytuację, w której dzieci i młodzież nie osiągają celów aktywności fizycznej wyznaczonych przez wytyczne WHO (Bull i in. 2020), co jest szczególnie widoczne w trakcie i po pandemii COVID 19 stawiają nowe wyzwania przed badaczami z różnych krajów.

W niniejszej rozprawie podjęto problem skuteczności krótkiego i atrakcyjnego 10-tygodniowego programu interwencyjnego ćwiczeń z urządzeniem generującym wibracje (VGD) i bez niego, prowadzonego w ramach zajęć szkolnych u młodzieży w porównaniu do zwykłego programu aktywności fizycznej oraz konsekwencji tego programu dla wybranych funkcji poznawczych.

Celem badania było sprawdzenie, czy istnieją różnice w wynikach wybranych funkcji poznawczych u uczniów uczestniczących w 10-tygodniowym programie interwencyjnym.

Badania przeprowadzono dwukrotnie, przed rozpoczęciem projektu (pre test) oraz po jego zakończeniu (post test) i wzięli w nich udział 15 i 16-letni uczniowie, zakwalifikowaniu do jednej z trzech grup: grupy kontrolnej (CG) bez dodatkowej aktywności fizycznej, grupy z dodatkową aktywnością fizyczną bez lokalnej wibracji (EG) oraz z dodatkową aktywnością fizyczną i zastosowaniem lokalnej wibracji (VEG). Poziom wybranych funkcji poznawczych oceniano za pomocą powszechnie stosowanych testów uwagi, szybkości przetwarzania zadań, sprawności koncentracji, dokładności, fluencji słownej, pamięci słownej, pamięci liczbowej itp.

Zgromadzone dane przeanalizowano z zastosowaniem podstawowych i zaawansowanych metod statystycznych. Oceniono istotność różnic między zmiennymi, związki zachodzące między nimi, zaś dla oceny wpływu zmiennych na sprawność koncentracji zastosowano analizę regresji krokowej.

Wyniki pokazują, że po 10-tygodniowym programie interwencji istotne statystycznie zmiany poziomu funkcji poznawczych częściej występują w grupie VEG, następnie w EG i co najmniej w CG. Poprawa stylu pracy (wykazana w wartościach procentowych) kształtuje się następująco: największą poprawę we wszystkich obszarach zaobserwowano dla wyników uczniów z grupy VEG, w dalszej kolejności w grupie CG i najmniej w grupie EG, co jest raczej zaskakujące i być może spowodowane czasem trwania interwencji (Haapala, 2012). Sprawność koncentracji związana jest głównie z prędkość pracy oraz innymi zmiennymi, zwłaszcza w grupach EG i VEG.

Podsumowując można stwierdzić, że istnieją dowody, że aktywności fizyczna z wykorzystaniem lokalnej wibracji może w większym stopniu niż tradycyjna aktywność fizyczna wpływać na zmiany poziomu funkcji poznawczych u młodzieży w stosunkowo krótkim okresie 10 tygodni. Stwierdzono też, że poprawa sprawności koncentracji następuje głównie poprzez poprawę dokładności w redukcji błędów. Aby lepiej zrozumieć wpływ aktywności fizycznej wzbogaconej o ćwiczenia z wykorzystaniem lokalnej na zmiany poziomu funkcji poznawczych potrzebne są dalsze badania z zaangażowaniem większej liczby uczestników.

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Appendices

Appendix 1: List of Figures and Tables

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Appendix 2: Vibration Generating Device

Figure A1: VGD smovey neuro VIBE small/light in comparison to smovey CLASSIC green (source: smovey GmbH with kind permission, 2022)

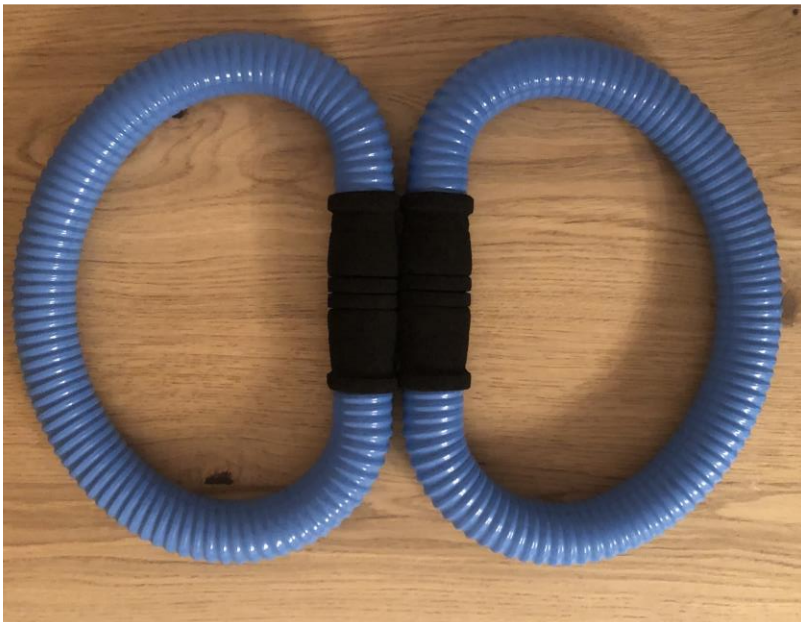

Figure A2: One pair of VGD smovey neuro VIBE small/light

Appendix 3: Test Worksheets

The worksheets were created in German and are shown here in the original language. Students also received the d2-R quick reference guide, the d2-R test sheet and blank sheets to complete the recall tests. Due to copyright, the sheets of the d2-R test are not cited.

Messbogen Forschungsprojekt BAfEP

Persönlicher Code SchülerIN:________________

Datum Messung:______________________________

Angaben zur Person: ALTER (J/M): _____________, GRÖSSE:_______________

GEWICHT:___________, Männl.: O Weibl.:O

Messparamater kognitiv:

I) Konzentrations- und Aufmerksamkeitstest d2-R, Kurzanleitung + Testbogen

II) Wörterlisten merken: 1 Blatt mit 20 Begriffen aus unterschiedlichen Themenbereichen und unterschiedlicher Länge. Begriffe 1 Minute lang einprägen, danach so viele Begriffe wie möglich aufschreiben, Reihenfolge egal (1 Minute). Der Test wird 3 x wiederholt.

Auswertung 1: ________________ Begriffe korrekt wieder gegeben.
Auswertung 2: ________________ Begriffe korrekt wieder gegeben.
Auswertung 3: ________________ Begriffe korrekt wieder gegeben.

II) Zahlenreihen merken: Es werden Zahlenreihen mit 6 Zahlen für jeweils 3 Sekunden gezeigt, anschließend 2o Sekunden warten und danach die richtigen Zahlen in der richtigen Reihenfolge nieder schreiben.

Auswertung: 1)

Zahlen 1)______r	Zahlen 4)______r	Pos: 1_____r	Pos: 4_______r
Zahlen 2)______r	Zahlen 5)______r	Pos: 2_____r	Pos: 5_______r
Zahlen 3)______r	Zahlen 6)______r	Pos: 3_____r	Pos: 6_______r

Figure A3: Worksheet page one

III) COWAT -Test

In einer Minute so viele Wörter mit möglich mit dem genannten Anfangsbuchstaben (außer Zahlen, Eigennamen und Wortkombinationen aus bereits genannten Begriffen) oder dem genannten Themengebiet nennen.

1) ______________ Wörter mit Anfangsbuchstabe F
2) ______________ Wörter mit Anfangsbuchstabe A
3) ______________ Wörter mit Anfangsbuchstaben S

IV) Akustischer Test (Neurologie)

In ruhigem Raum wird in Körpernähe immer das selbe akustische Signal abgegeben. Der Proband hat seine Augen geschlossen. Er versucht, mit seiner Hand die Tonquelle zu treffen.
Notiert wird der Abstand zur Signalquelle in cm, Durchführung 5 Mal an unterschiedlichen Positionen.

1. Position: _____________cm
2. Position: _____________cm
3. Position: _____________cm
4. Position: _____________cm
5. Position: _____________cm

V) Sensibilität Körper/ Hände

Ertasten von 2 gleichen Gegenständen (Holzstücke mit unterschiedlicher Oberfläche, gleiche Länge, 14 unterschiedliche Muster) in einer dunklen Tasche. Die Gegenstände müssen gleichzeitig mit rechter und linker Hand aus der Tasche genommen werden. Zeit: 2 min.

Ergebnis: _______________ Paare richtig ertastet.

Figure A4: Worksheet page 2

Appendix 4: Mean values and Standard Deviation (SD)

Table A 1: Mean and SD of test results of assessed variables

Variable	Test	All (N = 61)		CG (N = 16)		EG (N = 21)		VEG (N = 24)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Test processing speed (PTO)	Pre	161,16	26,93	171,50	29,18	147,05	22,58	166,63	24,62
	Post	196,49	32,89	197,31	26,75	178,52	27,62	211,67	34,00
Omission Errors (OE)	Pre	17,05	16,64	12,38	12,20	16,43	11,82	20,71	21,78
	Post	13,90	9,92	11,81	8,65	14,76	10,94	14,54	9,98
Confusion Errors (CE)	Pre	4,07	5,14	4,81	4,32	2,71	2,85	4,75	6,87
	Post	3,85	3,70	4,50	2,92	3,76	3,75	3,50	4,18
Concentration performance (CP)	Pre	140,05	35,39	154,31	29,42	127,90	28,45	141,17	41,49
	Post	178,74	35,76	181,00	27,18	160,00	33,92	193,63	36,02
Diligence in test processing (E%)	Pre	13,84	14,23	10,05	7,74	13,56	10,16	16,60	19,54
	Post	9,40	6,62	8,33	4,69	10,94	8,54	8,77	5,78
Variable	Test	All (N = 60)		CG (N = 15)		EG (N = 21)		VEG (N = 24)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Numeric memory test (DSRN)	Pre	4,83	1,47	5,40	0,91	4,33	1,74	4,92	1,41
	Post	5,17	1,20	5,67	0,62	4,81	1,57	5,17	1,01
Verbal memory test (IFRW)	Pre	28,65	4,93	29,10	4,68	28,09	6,14	28,87	3,97
	Post	31,98	5,15	31,40	4,91	31,43	6,43	32,83	4,01
Verbal fluency (COWAT)	Pre	40,50	6,36	40,40	5,18	39,52	7,63	41,42	5,93
	Post	43,75	6,90	38,87	3,58	44,71	7,48	45,96	6,66
Variable	Test	All (N = 68)		CG (N = 20)		EG (N = 21)		VEG (N = 27)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Sensitivity Test (ST)	Pre	3,75	1,86	4,55	1,93	3,29	1,85	3,52	1,70
	Post	4,69	1,98	5,20	2,42	4,38	1,96	4,56	1,60
Acoustic Test (AT)	Pre	11,44	5,89	11,29	5,09	13,64	7,42	9,84	4,66
	Post	9,99	5,35	12,03	5,16	10,21	5,44	8,31	5,05

Appendix 5: Declaration of Originality

I confirm that the submitted thesis is an original work and was written by me without further assistance. Appropriate credit has been given where reference has been made to the work of others.

The thesis was not examined before, nor has it been published. The submitted electronic version of the thesis matches the printed version.

Place, date Signature