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APPLICABILITY OF A NEW INTERNET-BASED COGNITIVE TRAINING PROGRAM: IMPLEMENTATION AND EFFECTIVENESS OF THE GO/NO-GO TASK

Master's thesis

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Running head: Applicability of a new internet-based cognitive training program

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Abstract

The purpose of this pilot study was to examine the effectiveness and applicability of a cognitive training based on a computerized Go/no-go task on inhibitory control, processing speed and executive control in young adults. Eleven individuals between the ages of 19-26 participated in a four-week long training, thirteen same age peers were recruited in a passive control group. In the beginning of the study all participants from training and control group were assessed with Trail Making Test (TMT) to specify the pre-testing level of inhibitory control, executive control and processing speed. After initial assessment participants from the training group performed short computerized Go/no-go task trainings five times a week during a four-week period whereas control group participants were on a passive waiting-list. After four weeks both training and control group participants were again assessed with TMT. The results showed that training on a Go/no-go task has a significant positive effect on inhibitory control – within four weeks inhibitory control had improved by 24% in the training group. Nonsignificant improvements in executive control were also notable in the training group. The processing speed of the training group individuals did not seem to either improve nor decline. Control group individuals however, performed significantly faster after four weeks during the re-testing. In conclusion, inhibitory control, a core component of executive functioning and an important contributor to overall well-being, academic and social functioning and quality of life, could be improved with our four-week long computerized training with Go/no-go tasks.

Keywords: Go/no-go, inhibitory control, processing speed, executive control, executive functions

Pealkiri: Uue veebipõhise kognitiivse treeningprogrammi rakendamine: Go/no-go ülesande rakendamise ja tõhususe uuring

Kokkuvõte

Käesoleva pilootuuringu eesmärk oli uurida Go/no-go ülesandel põhineva arvutipõhise kognitiivse treeningu efektiivsust ja rakendatavust. Treeningu efektiivsust noortel täiskasvanutel hinnati kolme kognitiivse võime – impulsikontrolli, infotöötluskiiruse ja eksekutiivse kontrolli – raames. Neljanädalasest kognitiivsest treeningust võttis osa üksteist indiviidi vanuses 19-26, passiivsesse kontrollgruppi kuulus kolmteist samas vanuses osalejat. Uuringu alguses viidi läbi eeltestimine kõigi uuringus osalejatega. Impulsikontrolli, eksekutiivse kontrolli ja infotöötluse hindamiseks kasutati *Trail Making Test*'i (TMT, punktide ühendamise test). Pärast esmast testimist sooritasid treeninggrupi liikmed viiel päeval nädalas nelja nädala vältel lühikesi Go/no-go ülesandel põhinevaid treeninguid. Kontrollgrupi liikmed treeninguid ei sooritanud. Nelja nädala pärast viidi treening- ja kontrollgrupi liikmetega läbi järeltestimine, milles kasutati TMT'i. Tulemused näitasid, et Go/no-go treening avaldas positiivset mõju impulsikontrollile: treeninggrupi liikmete impulsikontroll paranes neljanädalase treeningu järgselt 24% võrra. Treeninggrupi liikmete eksekutiivne kontroll paranes samuti mõnevõrra, kuid muutus ei olnud statistiliselt oluline. Treeningutes osalenud indiviidide infotöötluse kiiruses olulisi muutusi ei ilmnenud. Kontrollgrupi liikmed olid aga teistkordsel testimisel nelja nädala möödudes oluliselt kiiremad kui esimesel testimisel. Kokkuvõtteks, neljanädalase arvutipõhise Go/no-go treeningu järgselt paranes osalejate impulsikontroll, mis on oluline osa eksekutiivsetest funktsioonidest ning mängib rolli üldises heaolus, akadeemilises ning sotsiaalses toimetulekus ja elukvaliteedis.

Märksõnad: Go/no-go, impulsikontroll, infotöötluse kiirus, eksekutiivne kontroll, eksekutiivsed funktsioonid

Many neuroscientists and psychologists have believed that the core aspects of cognitive abilities are fixed from a young age with basically no room for improvement (Salthouse, 1991). Cognitive abilities such as memory, attention and information processing were thought to be determined during early development. The growing knowledge about brain has lead to new perspectives. It is now understood that with the right kind of activity and stimulation, different aspects of cognition can be improved: the brain can change and remodel itself (Bavelier, Green, Pouget, & Schrater, 2012; Bryck & Fisher, 2012; Chapman & Mudar, 2014; Hardy & Scanlon, 2009; Klingberg, 2010).

The growing development of new technology, including interactive multimedia software, combined with new development in brain science, has led to an explosion in using computer-based technology as a tool for cognitive training (Hardy & Scanlon, 2009). Previous results indicate that cognitive training can improve a wide variety of core cognitive skills in case of cognitive impairment as well as in normal cognitive abilities and children as well as in adults (Chapman & Raksha, 2014; Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Morrison & Chein, 2011; Schmiedek, Lövden, & Lindenberger, 2010).

Cognitive training should be customized for each person to enhance specific cognitive skills through brain-based learning techniques (Bavelier, Green, Pouget, & Schrater, 2012; Hardy & Scanlon, 2009). Typically, cognitive training consists of exercises that are designed to improve memory, attention, visual and auditory processing, listening skills, reading skills, self-control, processing speed, and other cognitive functions (Hardy & Scanlon, 2009). The improvement of these skills can help people do better at school or at work, live a more productive life, alleviate some of the ageing processes and increase their mental resilience (Chapman & Raksha, 2014).

Nowadays, most of the cognitive trainings can be done at home with the help of different computer programs. More so, there are many positive examples of different cognitive training programs (Gordon, Palmer, Liu, Rekshan, & DeVarney, 2013; Morrison & Chein, 2011; Au, Sheenan, Tsai, Duncan, Buschkuehl, & Jaeggi, 2014). However, there is still much to be learned about the kinds of training programs that provide meaningful changes. Chapman and Raksha (2014) state that „From a public health perspective, cognitive training will be deemed useful if the training has generalized benefits and builds cognitive capacities to support performance in day-to-day tasks“.

Executive functions (EFs)

Common targets for cognitive training are executive functions (EFs). EFs are a collection of related yet separable higher order cognitive skills (Miyake & Friedman, 2012). Core EFs include executive control, inhibition, and processing speed (Diamond, 2013; Miyake & Friedman, 2012). In general, EFs are a set of capabilities required to effortfully guide behaviour towards a goal, especially in no routine circumstances (Banich, 2009). EFs are thought to play a key role in intelligent behaviour. To be more specific, they make possible mentally playing with ideas; withholding response; meeting and adapting to novel, unanticipated conditions; resisting temptations; and staying focused (Diamond, 2013).

EFs develop for a long period of time, starting in infancy, exhibiting significant growth spurts during the preschool period and reaching competency in adolescence or young adulthood (Brych & Fisher, 2012). Successful functioning of EFs plays a critical role in several other domains, like theory of mind, self-regulation, and long-term memory retrieval (Levy & Anderson, 2002).

For example, EFs are believed to predict academic achievement and social functioning, health behaviour and stress regulation (Enriquez-Geppert, Huster, & Herrmann, 2013). EFs are vulnerable to external as well as internal factors, like stress, insomnia, chronic pain, depression etc. (Sandberg, 2014). On the other hand, interruptions in EFs reveal in behavioural and neurocognitive impairment (Enriquez-Geppert, Huster, & Herrmann, 2013). Poorer EFs have been associated with obesity, and substance abuse (Miller, Barnes, & Beaver, 2011). What is more, poor EFs often lead to poor productivity and difficulty finding and keeping a job (Bailey, 2007) whereas, better EFs predict a better quality of life (Brown & Landgraf 2010). It is therefore important to find ways to improve executive functions through various approaches, including brain training. However, these are only few of the many aspects that make EFs an interesting and relevant target for cognitive training.

Executive functions are a complex of cognitive processes, and therefore require coordination of several sub-processes. An imporant cognitive process that subserves higher-order cognitive domains, including executive functions, is processing speed. While processing speed and executive functions are distinct, processing speed has been noted as one of the basic cognitive processes driving executive functions (Tanner, 2009). Information processing speed is the amount of time needed to process a set amount of information (Kalmar & Chiaravalotti, 2007). Processing speed has been associated to the brain’s ability to efficiently and effectively orchestrate signals between neurons (Hancock, 2013). Therefore, processing speed is related to the efficiency of different occupational and everyday activities. What is more, together with working memory, processing speed has been found to affect other areas of cognitive performance, for instance learning, planning and attention (Hancock, 2013). Deficits in processing speed increase with age and occur in different illnesses, like Parkinson's disease (Ball, Edwards & Ross, 2007).

Another important core component of executive functions is inhibitory control. Inhibitory control is a major process mediated by the human prefrontal cortex. It refers to the ability to suppress intended or ongoing cognitive or motor processes, including actions that are inappropriate in a given behavioural context or that are not wanted because they interfere with the completion of a motor or cognitive task (Manuel, Grivel, Bernasconi, Murray, & Spierer, 2010; Mostofsky et al., 2003). It mediates the ability to make appropriate choices under changing situations (Konish et al., 1999). Inhibitory control helps to control one's attention, behaviour, thoughts and emotions to override a strong internal tendency or external temptation (Diamond, 2013). Findings from neuroimaging studies suggest that inhibitory control also develops across the developmental spectrum (Christ, White, Mandernach, Keys, 2013).

A. Diamond, a well-known EF researcher, provided a comprehensive review (2013) about executive functions, including inhibitory control. According to her, the term inhibitory control refers to different functions within the function. Inhibitory control of attention refers to the selectiveness of attention: it helps us to focus on or ignore what we choose and suppress or attend attention to other stimuli, based on our goal or intention. She brings out another aspect of inhibitory control which is cognitive inhibition. Cognitive inhibition is the ability to suppress prepotent mental representations, like unwanted thoughts and memories. Self-control is another expression of inhibitory control. That involves control over one's behaviour and emotions, resisting temptations and impulsiveness (Diamond, 2013). As can be seen, there are quite a few different aspects of inhibitory control, which can lead to a question, whether these aspects are dissociable from one another. Evidence indicates that diverse types of inhibitory control of attention and action appear to share substantially similar neural basis (Cohen, Berkman, & Lieberman, 2012). In fact, it has been found that attentional inhibition and inhibition of action are strongly correlated (Friedman & Miyake, 2004).

Deficits of inhibitory control have been associated with problems in behavioural regulation as well as a range of clinical disorders (Blair, 2001; Chen, Juan, Tzeng, & Hung; Woolley, Heyman, Brammer, Frampton, McGuire, & Rubia, 2008; Schachar, Tannock,

Marriott, & Logan, 1995; Booth et al., 2005). The mechanisms of inhibitory control are important in a range of behaviours to prevent execution of previously planned motor acts which are no longer necessary or appropriate (Juan & Muggleton, 2012).
Inhibitory control, namely the lack of it, has also been associated with recurrent intrusive thoughts that are apparent across different clinical disorders (Bomyea & Amir, 2011). Moreover, it has been found that improving inhibitory control through computerized training programs may have a positive effect in conquering intrusive thoughts (Bomyea & Amir, 2011).

Inhibitory control is also believed to be an important aspect of executive control. Executive control generally refers to the regulation of mental activity. Executive control processes include response monitoring and inhibitory mechanisms, switching and updating, playing a crucial role in complex cognition (Rubinstein, Meyer, & Evans, 2001; Karbach & Kray, 2009; Blakemore & Choudhury, 2006; Hsu, Novick, & Jaeggi, 2014). Executive control skills predict high level abilities, including memory, problem solving, and scholastic achievement (Hsu, Novick, & Jaeggi, 2014). The ontogenesis of executive control is relatively late (Hsu, Novick, & Jaeggi, 2014).

Training of cognitive abilities

Cognitive abilities change throughout life. Some cognitive abilities should reach a peak in people aged 20-30. However, most cognitive abilities of young adults do not reach the peak (De Luca et al., 2003; Luna, Garver, Urban, Lazar, & Sweeney, 2004). Therefore, improvements of cognitive abilities by cognitive training in young adults are attracting attention.

The question of whether inhibitory control can be improved with computerized training is understudied. The growing development of new technology and the availability of computers allow us to broaden cognitive training opportunities. However, there is still a need to investigate what kind of methods make a difference.

When information about brain training is searched on the Web, dozens of online exercises, games, software and apps that are designed to prepare brain to do better on any number of tasks appear. There is evidence that brain is modifiable and flexible in the context and in response to cognitive training. Evidence suggests that specially designed mental exercise, including cognitive training paradigms offer promise in improving cognitive brain performance in normal and clinical populations (Chapman & Raksha, 2014; Morrison &

Chein, 2011). However, lots of these brain training exercises on the Web do not have an evidence-based ground.

According to Sandberg (2014) there are two broad distinguishable training types: strategy approach and process-based approach. In the strategy approach, the focus is on improving cognitive performance through learning and practice with deliberate strategies. Strategy training studies are often focused on episodic memory, problem solving and reasoning (Sandberg, 2014). The process-based approach differs from the strategy approach by not including specific instructions about strategy. The aim is to strengthen cognitive processes central for the complex cognition. During past 3-5 years, there has been an increase in the number of studies investigating different ways of enhancing basic cognitive processes through extended practice on cognitively demanding tasks. The hypothesis has been that through improving basic cognitive capacities, such as executive functions, other cognitive abilities depending on them will benefit as well (Sandberg, 2014).

Therefore, cognitive training programs are often aimed to develop core capacities of general cognition that serve an important role as a basis in functioning of brain circuitry. For example, working memory is a core capacity that has been linked to the functioning of the frontal brain circuits and their connection with parietal attention circuits (Gordon et al., 2013). Working memory has received many attention when it comes to cognitive training. That direction is probably motivated by evidence which suggest that declines in memory are common with normal aging and brain injuries (Chapman & Raksha, 2014). While the plasticity of working memory training is highly reflected within the field of executive functions, plasticity of inhibitory control has not received such attention (Spierer, Chavan, & Manuel, 2013). The importance of inhibitory control in the context of everyday behaviour should not be underestimated, with the brain needing to guide behaviour in light of the continual change of the surrounding environment.

Diamond (2013) has reviewed different activities for improving executive functions in children and brings out the ones with the strongest evidence. These activities include CogMed computerized training, combination of computerized and interactive games, task-switching computerized training etc. She further states that with adults, the focus is more often on computerized training and although the results are rather optimistic, the design of the studies is often incomplete (for more details, see a review by Diamond, 2013).

As stated before, cognitive training programs are usually aimed to improve a certain aspect of cognitive functioning. That requires a variety of methods which is why a number of different computerized methods for the assessment and training of cognitive abilities have been developed. A widely known task is the Go/no-go task which has been used as an assessment instrument as well as a training method (Spierer, Chavan, & Manuel; Benikos, Johnstone, & Roodenrys, 2014).

Go/no-go task. The Go/no-go is a task in which stimuli are presented in a continuous stream and participants perform a binary decision on each stimulus. The stimuli are presented in different ways: some stimuli contain only the target, some stimuli contain the target and noise elements, and some contain noise elements only. One of the outcomes requires participants to make a motor response (Go), whereas the other requires participants to withhold a response (No-go). Accuracy and reaction time are measured for each event. Go events typically occur with higher frequency than no-go events. Go/no-go task has been asserted to measure inhibition, behavioural inhibition, response inhibition and reaction time. The task has proven convergent validity (at least moderate correlations with executive functions test like Trail Making Test part B, Wisconsin Card Sorting, Stroop Color-Word test) and test-retest reliability (Langenecker, Zubieta, Young, Akil, & Nielson, 2007; Votruba, et al., 2013).

There is a small variety in Go/no-go tasks. The cued Go/no-go task (Fillmore, 2003) is used to measure impulse control by the ability to inhibit instigated, “prepotent” responses. In this type of Go/no-go task, the preliminary Go/no-go cue is presented before the go/no-go target. The cues provide information concerning the probability that a Go/no-go target will be presented. The cue-target relationship is manipulated so that the cues have a high probability of correctly signalling a go or no-go target (valid cues), and a low probability of incorrectly signalling a target (invalid cues). Valid cues tend to facilitate response inhibition and speed response execution, whereas invalid cue cues tend to impair response inhibition and slow response execution (Fillmore & Weafer, 2013).

The Go/no-go task has a long history and it is used in different areas, like bilingualism, neuropsychology, visual-word recognition, masked priming, speech production, semantic categorization, clinical visual-field testing, object recognition, and recognition memory. The Go/no-go procedure also has a long tradition in animal behaviour research (Gomez, Ratcliffe, & Perea, 2007). It is also used as an assessment tool in clinical populations. The cued Go/no-go task has been used in assessing impulse control in clinical populations of children and young adults with ADHD (Roberts, Fillmore, & Milich, 2011). The Go/no-go is a cognitive task aimed at determining the ability of an individual to inhibit a response deemed inappropriate. What is more, experimental paradigms measuring response times (RTs) often assess how the information-processing sequence of perception, decision making, and action are organized (Georgiou & Essau, 2011). The task has also been used as a method for training cognitive abilities. In fact, it has been proposed that since the the Go/no-go task involves very directly motor inhibitory control, it is primarily used to train this aspect (Spierer, Chavan, & Manuel, 2013). Spierer and colleagues (2013) have presented a small review of cognitive training programs concerning inhibitory control, where the Go/no-go task is widely represented. Using Go/no-go as a training method has given some evidence on the validity of the task in measuring inhibitory control and impulsivity.

Trail Making Test. In the assessment of executive functioning a Trail Making Test (TMT) is widely accepted by both researchers and clinicians. The test was introduced in 1938 by Partington. It is mostly used as an indicator of speed of cognitive processing and executive functioning but has also been applied to measure aspects of attention, visual search, psychomotor speed, perceptual speed, working memory, flexibility, inhibitory control, mental tracking (Salthouse, 2011; Sánchez-Cubillo et al., 2009).

The Trail Making Test consists of two parts. In part A (TMT-A) the task is to draw a line to connect circled numbers in a numerical sequence (i.e., 1–2–3, etc.) as fast as possible. In TMT-B the task is to connect circled numbers and letters in an alternating numeric and alphabetic sequence (i.e., 1-A–2-B, etc.) as fast as possible.

The performance of the Trail Making Test as a whole depends largely upon processes involved in visuoperceptual abilities (Ehrenstein, Heister, & Cohen, 1982). The score of TMT-A has been found to be affected by processing speed and visual attention (Sánchez-Cubillo et al., 2009; Schad et al., 2014). TMT-B is more complicated and has therefore been proposed to involve additional executive function demands, including behavioural inhibition (Sánchez-Cubillo et al, 2009). The TMT-B has been found to mainly require working memory and task-switching ability. More so, TMT-B is believed to have a heightened demand on executive control and B-A difference score is believed to provide a relatively pure indicator of executive control abilities independent of processing speed (Müller et al., 2014; Sánchez-Cubillo et al., 2009; Schad et al., 2014).

Training of inhibitory control and processing speed

Research on inhibitory control mainly rely on Go/no-go paradigms requiring speeded responses to one class of stimuli (“Go”) while withholding responses to another class of stimuli (“No-Go”) (Manuel, Grivel, Bernasconi, Murray, & Spierer, 2010; Mostofsky et al., 2003; Christ, White, Mandernach & Keys, 2001). Studies have shown that training improves Go/no-go proficiency (Manuel et al., 2010). As stated before, there are many positive examples of the effectiveness of cognitive training programs. Yet, there are results that indicate the contrary. For example, Enge and colleagues (2014) found that inhibitory control training did not improve the results when compared to the control group. Thorell and colleagues (2009) state that at least three different types of training effects can be found: effects on the task trained on, effects on non-trained tasks and transfer effects to related cognitive abilities. In light of that, some authors have claimed that training effects on a Go/no-go task do not transfer to other executive tasks (Spierer, Chavan, & Manuel, 2013).

To conclude, although interventions for training inhibitory control are available and show promising effects of cognitive training, there are still inconsistencies and a lack of scientific proof of the effectiveness of those interventions and the trainability of inhibitory control whatsoever.

In contrast to inhibitory control training, processing speed training has often been linked to transfer effects on other cognitive abilities. The main aim of processing speed training is to improve the capacity of mental processing such that trainees can process increasingly greater amount and more complex information over shorter periods of time (Ball, Edwards, & Ross, 2007). In spite of the tight relation to other cognitive capacities, there is a cognitive training paradigm that is directly targeted at processing speed training. Processing speed trainings usually involve target detection, identification, discrimination, and localization (Ball, Edwards, & Ross, 2007). Studies regarding this paradigm have shown that the trainings transfer to different everyday activities and quality of life in older adults (Burge et al., 2013).

Since information processing speed is closely linked to other cognitive abilities, there is no pure measure of processing speed and tasks designed to improve information processing speed require and affect other cognitive skills such as attention and memory (Ball, Edwards, & Ross, 2007). It has been suggested that any type of training that is used to improve processing speed may affect cognitive domains. On the other hand, slowed information processing speed has an effect on tests that measure a wide variety of functioning (Hancock, 2013). This makes processing speed stand out comparing to other cognitive abilities because previous studies have suggested that cognitive training is very specific to the ability trained, with little transfer of training to untrained cognitive domains (Ball, Edwards, & Ross, 2007).

Cognitive training is complex and there are many factors to take into account. It is important to consider the development of the trained abilities. As stated earlier, different component of EF continue to develop during young adulthood. Yet, there are controversial results regarding if and when the development reaches its peak and what kinds of trainings provide most beneficial results in that particular age group. One of the reasons of controversial results is probably different methodological approaches used in the studies. For example, across different studies of the effectiveness of the cognitive trainings the number of participants varies between 3 to 36 (Au et al., 2014; Morrison & Chein, 2011). The age of participants in trainings directed to young adults ranges from 19-25, the majority of studies have included participants aged 23-25 (Melby-Lervåg & Hulme, 2013). Moreover, the length of the training period across studies varies, ranging from 8 to 30 sessions delivered over one to two months (estimated average of 5 weeks) in 15 to 60 min duration (Chapman & Mudar, 2014; Melby-Lervåg & Hulme, 2013; Morrison & Chein, 2011).

Another issue concerning controversial results could be linked to the absence of a control group. Melby-Lervåg and Hulme (2013) state in their article that „The performance of a trained group needs to be compared with one or more suitable control groups“. Their main concern is that without a control group, improvements between pre-test and post-test in a trained group may simply reflect maturational changes or practice effects. More so, they tone that each group should be tested before and after training, because analyzing changes between these scores increases the power to detect a training effect.

“ARU” – The cognitive training program

In early 2015 a new internet-based cognitive training program “ARU”, developed by MTÜ Peaasi and OÜ CognUse was launched. After still ongoing beta-testing the computer-based cognitive training program “ARU” will freely be available via the PEAASI.EE website. Cognitive trainings in this computer program are ought to improve different aspects of cognitive abilities in Estonian speaking youth. These cognitive trainings in “ARU” consist of different types of cognitive exercises – e.g. Go/no-go task, n-Back task and Wisconsin task.

Objective and hypothesis

The main aim of this study is to test the applicability and effectiveness of the one specific cognitive training in “ARU”: Go/no-go task. The specific interests were whether the trainings could have some impact on the different aspects of executive functioning - mainly to inhibitory control, processing speed and executive control. In order to address this research question the following specific hypothesis were tested:

After 4 weeks of training on the computerized Go/no-go task:

1. There are no siginificant changes in processing speed after four weeks in control group participants.
2. After four weeks of trainings the processing speed of the participants in the training group is improved.
3. There are no siginificant changes in inhibitory control after four weeks in control group participants
4. After four weeks of trainings the inhibitory control of the participants in the training group is improved.
5. There are no siginificant changes in executive control after four weeks in control group participants
6. After four weeks of trainings the executive control of the participants in the training group is improved.

Furthermore, the usability of the program is adressed in order to gather feedback and recommendations for the program.

Method

This pilot study was carried out between 01.01.2015 – 1.04.2015 in Estonia. The study was approved by the Tallinn Medical Research Ethics Committee. All participants provided informed consent to participate in this study.

Sample

The participants were recruited via advertisements from universities of Tallinn and Tartu. Thirty-three participants were initially recruited to participate in the study and were randomly assigned to either the training group or the control group. However, the final sample constituted of twenty four Estonian speaking young adults aged 19-26 (mean age 23.6, *SD* = 1.79). 50% (n = 12) of the participants were male. For an overview of the study design and allocation of participants, see Figure 1.

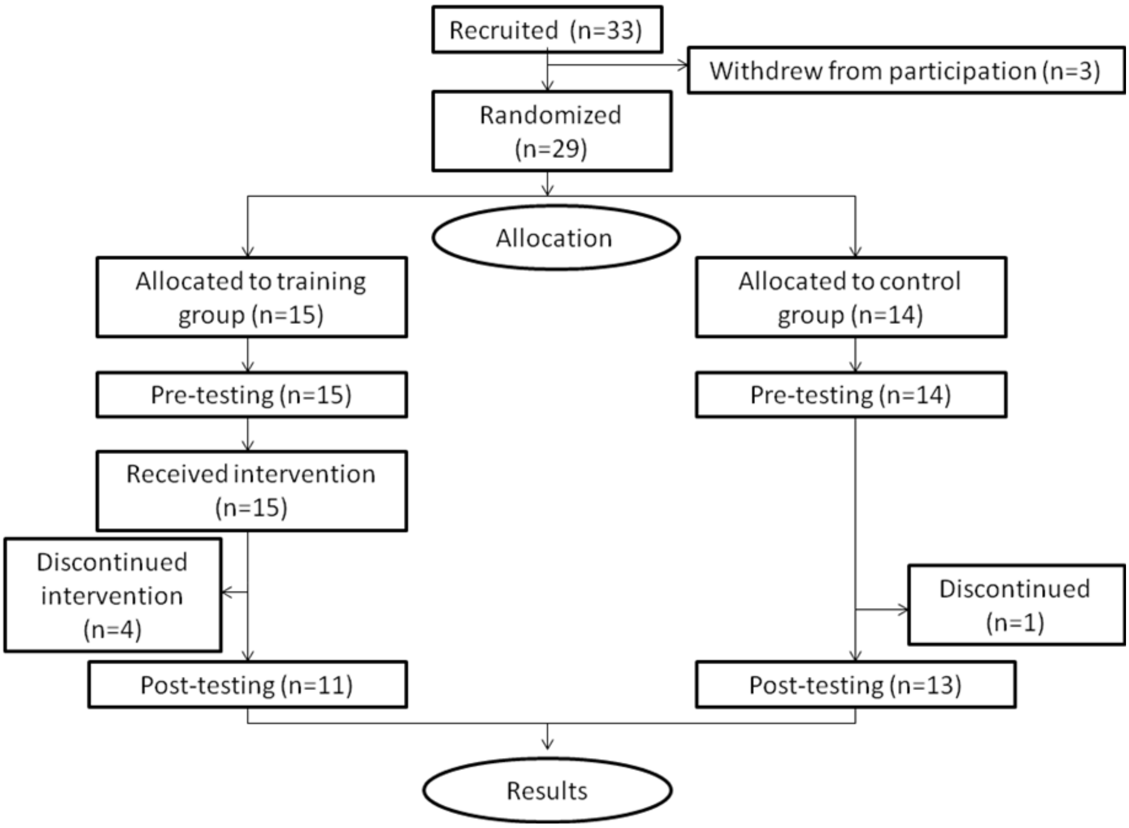

Figure 1. Study design. *n* – Number of participants.

Table 1 details the demographics of the training group and the control group separately. The training group and control group did not differ significantly in terms of age and gender. More so, control group and training group were also similar in their pre-training inhibitory control, executive control and speed of processing.

Table 1. *Demographics*.

Group	**n**	**Age in years**	**SD**	**Gender**
Training group	11	23.53	2.31	45.5% (n=5) male
Control group	13	23.78	1.29	53.8% (n=7) male

Note. *n* – Number of participants.

Measures

Trail Making Test. For the assessment of effect of training on different aspects of executive functioning Trail Making Test (TMT) was used. Measures of inhibitory control, processing speed and executive control (proposed by Sánchez-Cubillo et al., 2009) were obtained. The test was instructed according to the guidelines provided by Tombaugh (2003) to all the participants. Total time in seconds for both parts of the test was recorded. The norms proposed for 18-89 year olds by Tombaugh (2003) were used.

Computerized version of the Go/no-go task. For training the computerized version of the Go/no-go task was used. It was based on the well-known task in which stimuli are presented in a continuous stream and participants perform a binary decision on each stimulus. One of the outcomes requires participants to make a motor response (Go), whereas the other requires participants to withhold a response (No-go).

Questionnaire. Qualitative data, subjective evaluations from the participants concerning the applicability of the training program was collected via a questionnaire that included mostly open questions, like “What did you like about the training program?” or “What should be improved in the training program?”. The data from the questionnaires contained mainly 4 types of answes: 1) difficulty of the tasks; 2) design of the tasks; 3) performance on the tasks; and 4) technical support.

Procedure

Data was collected in three parts: pre-testing, training period and post-testing. Figure 2 provides a brief overview of these stages. All participants were administered tests at the beginning and at the end of the study. Assessment was conducted individually with each of the participants in a quiet room. Each of the participants met individually with the researcher. Before and after the training period, the same researcher assessed each participant. The evaluation procedure was administered in a fixed sequence. One meeting lasted about 15 minutes. During the meetings, all participants filled a questionnaire concerning their demographics and then were tested with the TMT. Participants in the training group then received instructions to start to perform the cognitive trainings. The participants in the control group were offered to start the training after the waiting period of four weeks. After four weeks all of the participants completed the same tests as during the pre-testing stage. Subjective evaluations concerning the training program were collected via questionnaire.

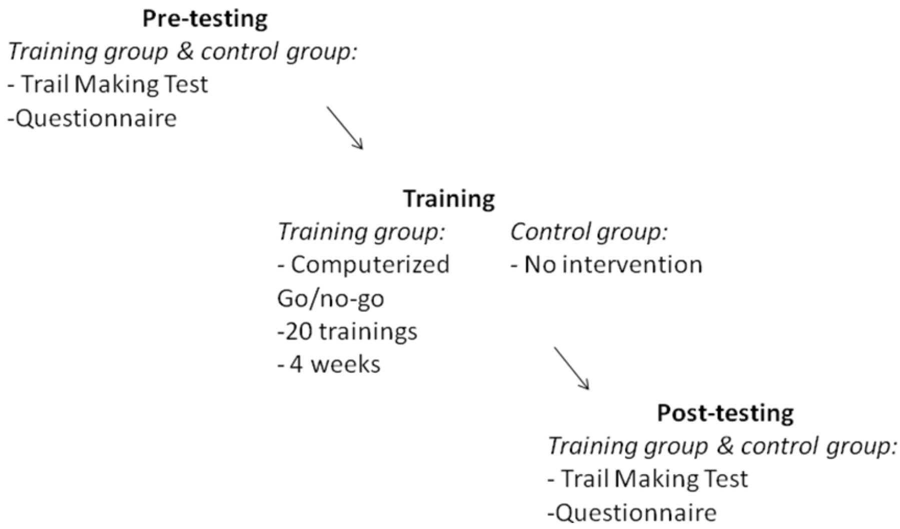

Figure 2. Data collection stages and measures.

Training procedure. The training was accessible via Peaasi.ee server on the Internet. Each of the members in the training group conducted their training when and where it seemed suitable. All the participants were advised to perform the training in a rested state and an interference-free environment. The participants were asked to perform 20 computerized trainings over 4 weeks 5 trainings in a week. Each training took approximately 5 minutes to complete. The training involved different Go/no-go tasks, including cued Go/no-go. An example of a Go/no-go training task is provided below (see Figure 3). The training varied: auditory as well as visual stimuli were used. The severity level of the tasks increased consistently. The complexity as well as the parameters of the training was altered during the training. The conditions were defined before the study. The results were saved by the program.

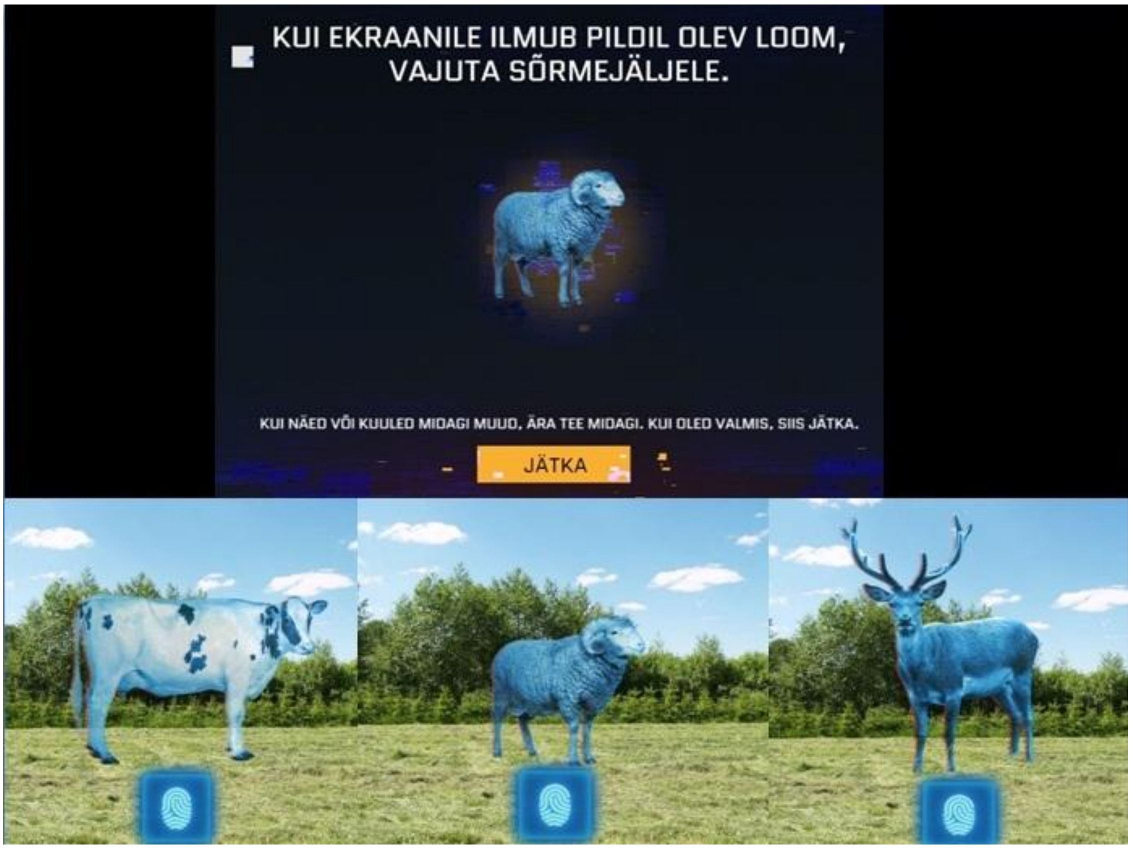

Figure 3. Example of a Go/no-go training task.

All of the participants in the training group finished all 20 trainings. The trainings were completed in the given time period of four weeks, *M* = 30.09 days (*SD* = 2.08). Pre- and post-testing was conducted at a similar time-range of *M* = 35.48 days (*SD* = 1.62) for both groups. The role of the control group was passive; the participants only took part in the pre- and post-testing - with no training between – at the same time-point as the training group.

Data analysis

The data was analyzed using IBM SPSS Statistics 20.0 programme (IBM Corporation, 2011). Shapiro-Wilks W test was used to control the distibution of the data. The test is particularly suitable because Shapiro-Wilks W is limited to "small" data sets. The results of the test showed that some of the data was not normally distributed and therefore, non-parametric data-analysis methods were used.

Differences in TMT were evaluated using a Mann-Whitney U-test for comparing the two groups. Wilcoxon's signed-ranks test was used for intragroup changes. The analysis was conducted at .05 significance level.

Results

The main results of the effect of the training program on processing speed, inhibitory control, and executive control are provided below. Lower value indicates faster performance and thus refers to better outcome.

Processing speed

Figure 4 details pre- and post-training results of processing speed measured by TMT-A. We found that compared to pre-testing control group performed significantly faster during post-testing ($Z = 2.69$, $p < .01$, $r = .56$). The processing speed of the training group was also improved but the gain in the training group was not statistically significant. However, when further analyzed with Mann-Whitney *U*-test, the results suggested that the difference between the improvement of processing speed in the control group and in the training group did not reach statistical significance.

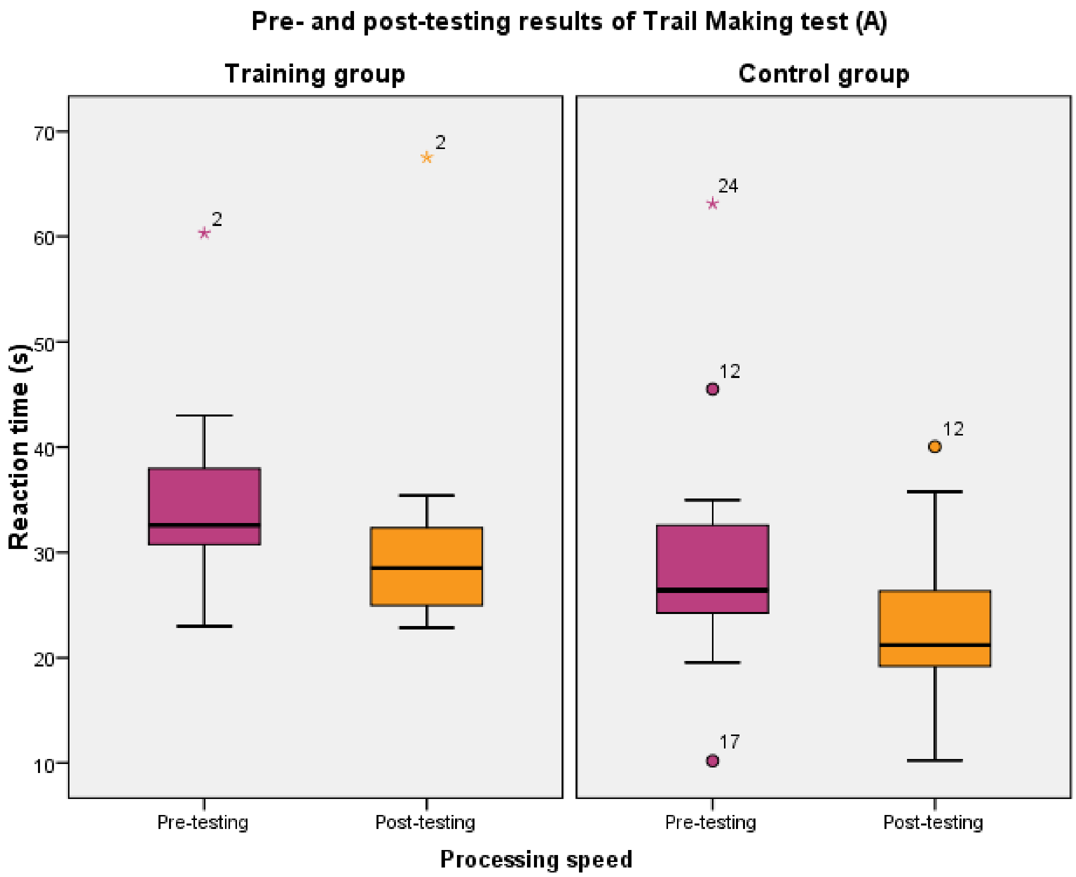

Figure 4. Pre-testing and post-testing mean reaction times and standard deviations of processing speed measured by TMT-A.

Inhibitory control

Figure 5 details pre- and post-testing results of inhibitory control measured by TMT-B. As can be seen in the figure, the groups developed in opposite directions. While the change is not significant and thus cannot be generalized, in our pilot study inhibitory control of the control group is seemingly better during pre-testing compared to post-testing. However, our data shows that there was indeed a significant improvement in inhibitory control after four weeks of training in the training group ($Z = 2.13$, $p < .03$, $r = .44$). According to guidelines from Cohen (Kinnear & Gray, 2010), the effect size was moderate.

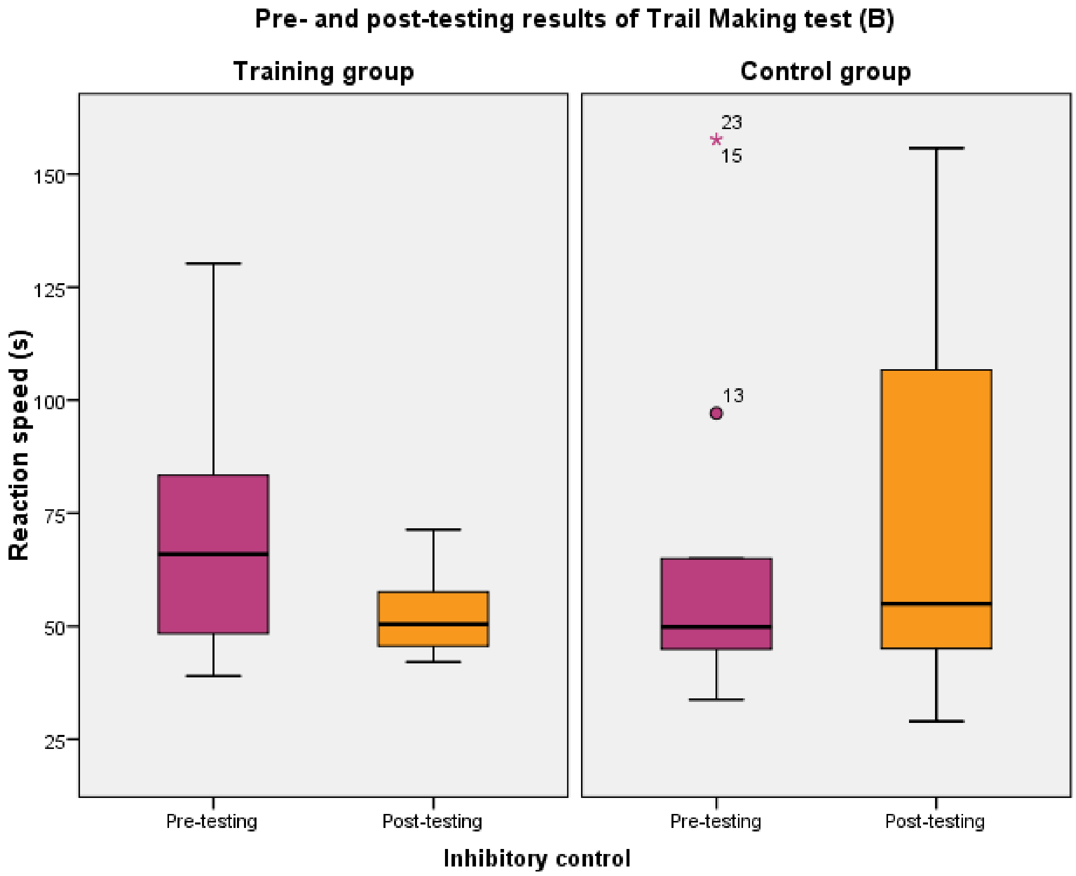

Figure 5. Pre-testing and post-testing mean reaction times and standard deviations of inhibitory control measured by TMT-B.

Executive contol

Figure 6 details the pre- and post-testing results of executive control computed from TMT-B and TMT-A difference. The executive control of the control group participants stayed at a similar level thoughout the four-week period. Although the training group showed some improvement in executive control after four weeks of training, the gain did not reach the level of statistical significance and thus is only illustrative for the present sample.

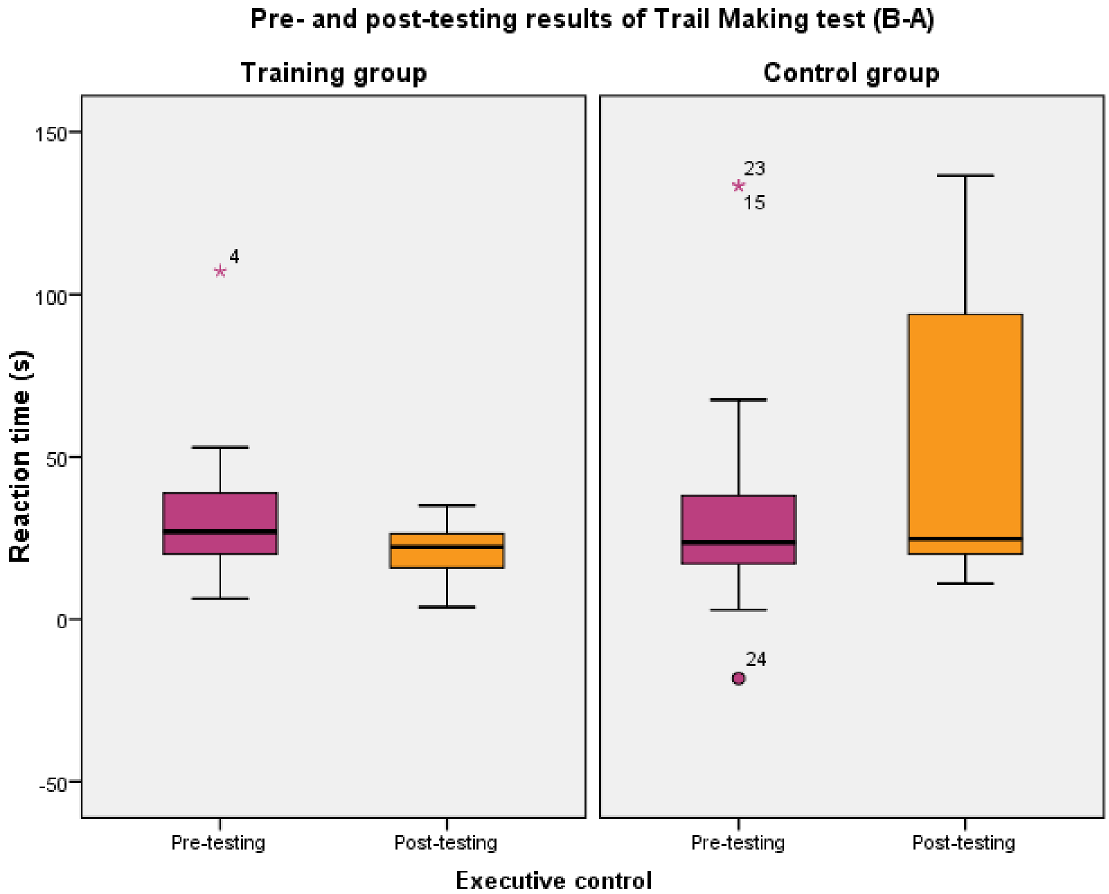

Figure 6. Pre-testing and post-testing means and standard deviations of executive control computed from TMT-B and TMT-A difference.

Applicability of the Go/no-go training

The subjective and qualitative data from the participants provided good feedback about the applicability of, and possible developments for the training program. Concerning the difficulty of the tasks, about half of the participants in the training program brought out that the training tasks were too simple or that they would have expected a higher degree of difficulty. However, few of the participants complimented the tasks on the rising level of difficulty. About half of the participants complimented on the design of the task, claiming it to be pleasant and attractive. Some of the participants recommended to use a greater variability of the stimulus. Performance on the task was evaluated as easy to access, comfortable and interesting. According to most of the participants, the instructions were clear and understandable. Concerning the technical support, some of the participants experienced difficulties accessing the training via certain browsers. However, this problem was surpassed. Many of the participants would have liked a reminder to perform the training. Some of the participants would have liked an opportunity to perform the training on their mobile phone, in addition to the computer. Overall, the participants were satisfied with the training and would continue to train their cognitive abilities in the future.

Discussion

The primary focus of this study was to evaluate the effect of intense, adaptive computerized cognitive training on processing speed, inhibitory control and executive control. Our data showed that in young adults inhibitory control can be improved with 4 weeks of training on the Go/no-go task: the training group improved significantly on the non-trained tests. In the non-trained test, the stimuli, presentation and response modules vary from the tasks used in the training programme. The results are also consistent with the findings that training specific cognitive abilities improves performance in tasks that share common underlying demands and processing components, and that training executive processes at basic level (Go/no-go task) transfers to other tasks (Oei & Patterson, 2013; Benikos, Johnstone, & Roodenrys, 2014; Verbruggen, Adams, & Chambers, 2012). Compared to the test-retest differences in the training group, the improvement on the measures of inhibitory control was 24% with moderate effect size. There were no significant changes in inhibitory control of the training group, which further supports the argument that the improvements in the training group were induced by the training program, and were not a result of normal development. The findings are consistent with previous evidence showing that cognitive abilities can be improved via training (Chapman & Raksha, 2014; Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Morrison & Chein, 2011), and adds to the short list of studies that have investigated the effects of inhibitory control training that found positive outcomes (Manuel et al., 2010; Berkman, Kahn, & Merchant, 2013). While some authors have argued that cognitive training is very specific to the ability trained, the results are somewhat controversial to the existing literature on Go/no-go training (Ball, Edwards, & Ross, 2007). Thorell et al. (2009) showed that training on a Go/no-go improved inhibitory control on the trained task and did not transfer to other tasks.

The study also investigated the effect of Go/no-go training on processing speed. The results concerning processing speed were unexpected: compared to pre-testing control group performed better during post-testing. However there was no significant change in the processing speed of the training group. There are several approaches that could explain these results. Firstly, considering that TMT-A is a test with little complexity, and that there was 4 weeks between the pre- and post-testing, the improved results could be associated with learning effect. Indeed, de Oliveira and colleagues (2014) found that comparing to other tests, including TMT-B, TMT-A was the only one in which learning effect was demonstrated. However, question remains why there wasn't an improvement of processing speed in the training group. One possible explanation is that performance on the TMT-A post-testing was influenced by inhibitory control training: the participants in the training group could have been more cautious and less impulsive to prevent making any mistakes due to improved inhibitory control. This is in line with Morrison & Chein (2011), who believe that similarly to the placebo effect, participants may anticipate the goals of the training and therefore put forth a greater effort during post-testing (Morrison & Chein, 2011). The results could also be explained by difference between experts and novices. It has been found that experts, in this case participants in the training group, spend more time before starting to solve the task, and take more time to check the course of the task (Hardin, 2002).

Another objective of this pilot study was to analyze the effect of Go/no-go training on executive control. Similarly to the inhibitory control measures, after 4 weeks of training the training group showed some improvement in executive control, however because of the lack of statistical significance these results describe only the present sample and are not generalizable to overall population.

Although this was a pilot study and the sample of the study was small, we can still conclude that four weeks of training elicits moderate improvements in inhibitory control. According to the literature, there are many factors that might affect the training outcome. For example it has been found that short-term performance gains can be related to variations in motivation, level of investment, adjustments of attention, automated processes, and task strategies (Enriquez-Geppert, Huster, & Herrmann, 2013; Morrison & Chein, 2011).

Executive functions training has also been associated with the amount of time spent working on those skills (Diamond, 2013). The training procedure of the program was set up similarly to other training programs. The duration of the training was approximately 4 weeks with approximately 5 trainings per week. However, the time spent on one training was relatively short (approximately 5 minutes) (Chapman & Mudar, 2014; Melby-Lervåg & Hulme, 2013; Morrison & Chein, 2011). This importance of the duration of a single training has found confirmation in a study by Klingberg (2010) where 10 minutes of unsupervised daily cognitive training three to four times per week did not result in any measurable cognitive effects. More so, Lampit, Hallock, & Valenzuela (2014) have argued that training more than three times per week is specifically ineffective. The results of our study do not support these findings and give reason to presume that short duration cognitive trainings at least five time a week during a four-week period are effective. This is also supported by the subjective evaluations by participants who evaluated the programme as easy to access, comfortable and interesting, pleasant and attractive. However, the minimalistic settings of the training procedure could have been one factor that held back greater improvement.

Another factor concerning the methodology of the training program is the difficulty level of the program. Previous studies have shown that it is important to adapt the difficulty level so that the training would be at an optimal level throughout the training period (Jaeggi, Buschkuehl, Jonides, & Perrig, 2011). The participants in the study approved the increasing difficulty of the training. However, it seems that the cognitive abilities of the participants were underestimated, and the training was therefore at times too simple. This knowledge provides good implications for developing the progam. The solution could be, for example, increasing the number of stimules and reducing the time for displaying the stimulus or the window of reaction.

Computerized cognitive training is a rapidly evolving field and although the amount of research in this field is increasing, much of the evidence is still controversial. Therefore, it is important to analyze new cognitive trainings and contribute to the already existing knowledge about the effectiveness and applicability of these programs. It is important to map the cognitive abilities that different exercises enhance and the amount of improvement achieved over an intensive training period. The rationale of creating new and effective cognitive trainings is that executive functions, including inhibitory control, executive control and processing speed are crucial for the support of a wide variety of everyday tasks. Ultimately, the goal of cognitive trainings is to further improve or support cognitive abilities at healthy levels for longer portions of the life span.

Limitations

The current results are preliminary and have several limitations. The first limitation is that the conclusions from the study are limited by the low number of participants. Furthermore, there was only a passive control group and no follow-up. Without any long-term follow-up study, it is not possible to determine whether the improvement observed in the present study is time limited or whether it represents an enduring change in underlying ability. Another issue is the small number of measures: this does not allow us to make further statements about the effect of the training program on other cognitive abilities. More so, TMT has been associated with various cognitive abilities which does not allow us to make bold conclusions about the effect of the training on named abilities. What is more, there is no adequate measure of the impact of the training on everyday life. Another concern to this and other studies of training programs is the influence of external variables, like motivation, attention etc. A challenge for future research would be to take these variables into account. Although a moderate improvement as a result of the training was found, a challenge for future research will be to identify protocols that might generate greater positive effects.

Conclusion and future directions

Our results indicate that the computerized Go/no-go training in “ARU” is applicable and effective for young adults. The results showed that 4 weeks of training on a Go/no-go task result in improved inhibitory control as during re-testing training group performed significantly better on the non-trained test used to measure inhibitory control. Although preliminary findings are promising, future studies should involve more participants to be able to make more profound conclusions. It is recommended to include more tests to pre- and post-testing stages to ensure a comprehensive neuropsychological assessment. Implementation of the training should be considered for clinical populations since some disorders, like schizophrenia, OCD, ADHD, and personality disorders have been linked to deficits in inhibitory control. Heightened impulsivity and inefficient inhibitory control have been considered to be risk factors for unhealthy eating and obesity and are associated with several facets of unhealthy eating, including overeating in response to external food cues and negative emotional states (Jasinska et al., 2012). Thus, one potential future direction of the training program is to test the effectiveness of the Go/no-go training on eating disorders in collaboration with the Tallinn Children’s Hospital’s eating disorders department. To conclude, this study was conducted to investigate the effectiveness and applicability of only one module of the comprehensive „ARU“ program. The focus of future research will be on Go/no-go as well as other modules and the program as a whole.

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