1 Intervention Development Protocol

2 'Train your Mind' program: Enhancing Executive Functions among Dutch Elementary School Children:

3 systematic development

4 Joachim Bervoets1, Lisa M. Jonkman2, Sandra Mulkens3, Hein de Vries4, and Gerjo Kok1

1 Department of Work & Social Psychology, Maastricht University, P.O. Box 616, 6200 MD Maastricht, The Netherlands
2 Department of Cognitive Neuroscience, Maastricht University
3 Department of Clinical Psychological Science, Maastricht University
4 Department of Health Promotion and Education, Maastricht University

Correspondence: j.bervoets@maastrichtuniversity.nl
Universiteitsringel 40, 6229 ER Maastricht; P.O. Box 616, 6200 MD Maastricht
Phone: +31433884342

5 Abstract

6 Background: Executive functions are higher cognitive control functions, consisting of inhibitory control, working memory, and cognitive flexibility, and are central to academic performance, and a healthy and successful life. While it has been shown that executive functions are trainable, how such improvements translate into everyday behaviors is not yet fully understood. The current project aimed to develop an intervention capable of enhancing executive functions among children aged 9 to 11. Subsequently, we hypothesized these improvements in EFs would lead to improved self-control, emotion-regulation, and attention (timely given the current potential rise in attentional problems); which in turn translate to more healthy behaviors in daily life, specifically physical activity and healthy eating – which is especially interesting given the recent rise in (childhood) obesity. To further stimulate the development of the latter behaviors, personalized tailored feedback was provided in the fourth and final module, eHealth.

7 Objectives: The present paper describes (1) what EFs are, why they matter in life, and how they can be trained and (2) the development of the Train your Mind intervention.

8 Methods: The design of this intervention, and the development of the program materials, was guided by the Intervention Mapping framework.

9 Results: A multi-component intervention was composed, including: (1) focused physical exercise (kung fu), cognitive games, (3) socio-emotional development, and (4) eHealth. All four components received
positive feedback during pilot-testing in terms of user friendliness (readability, graphics), gameplay (clear instructions, fun), and feasibility (for teachers).

Conclusions: The current literature base seems to suggest a multi-modal approach (cognitive, socio-emotional, and physical) may hold promising potential for the purpose of training executive functions, and perhaps even attain the much-desired broad transfer (practical translation into daily life), which, to date, has not been demonstrated before. In sum, encouraging the development of executive functions could yield great benefits in terms of academic performance, (physical and socio-emotional) health, and decreased risks during adolescence. Even though IM could not be applied completely, the overarching framework and various steps, provided guidance in developing and planning the intervention.

Trial registration: NTR 5804 (Nederlands Trial Register)

Keywords: Executive Functions, Children, Socio-Emotional-, and Cognitive Development, Academic Performance, Physical Activity, Healthy Eating, eHealth, Behavior Change, Intervention Mapping

Introduction

The current paper describes the underpinning theoretical structure and development of the school-based intervention 'Train your Mind' (TyM); a program that aims to enhance 'executive functions' (EFs) among 9-11-year old children. First, we describe what EFs are and why they matter in life. From this follows that EFs are strongly linked with healthy behaviors, which motivates us to target healthy behaviors as well in the intervention; a purpose for which tailored feedback via eHealth offers an ideal cost-effective platform [1]. At the core of the program, however, three modules are designed to train EFs: focused physical exercise, cognitive training, and socio-emotional development. We hypothesize that strengthened EFs mediate improvements in healthy behavior, as well as directly foster attention, emotion-regulation, and academic performance. As such, the current intervention’s aim was primarily two-fold; (a) to train EFs, and (b) to foster healthy behaviors in daily life. The rationale for this focus is clarified in the theoretical framework of the study, as outlined in the background section. Subsequently, we delve deeper into the design of the
intervention. How does the current literature propose EFs are trained? Considering the relative novelty of
the sub-field (of training EFs) and lack of evidence for broad transfer (increased EFs effects that reach
farther than for example the sub-EF working memory, and also affect daily life in a meaningful way, e.g.,
healthier eating), we opted for a multi-component approach. The over-arching idea was that these
components build on one another and strengthen each other’s effect synergistically. Such an integrated
multi-dimensional approach is, according to the most recent literature, the most effective in terms of
fostering broad transfer [2, 3], i.e. improvement on outcomes beyond EFs. To this day, however, few
studies have adopted such an approach [3], though it definitely merits a fair attempt given the multitude
and relevance of potential positive outcomes. Broad transfer embodies how cognitive development can
translate to practical relevance, in that children will be better able to govern their behavior, and
consequently, on the mid-long term, perform better academically [4], regulate their emotions more
effectively [5], be more physically active [6], and eat more healthily [7]. On the longer term, potential
beneficial practical effects can include less risky behaviors (e.g., unsafe sex, risky driving, substance abuse)
during adolescence, but also higher education, job income, and general mental health, during adult life [8,
619]. The development of this intervention was guided by the protocol 'Intervention Mapping' (IM)[10].
Given the magnitude of the intervention and effect-study, the current paper shall focus solely on the
development of the intervention, while the accompanying study design (13 primary schools, 34 groups,
800 pupils) is described in a separate paper.

While taking into account that strengthened EFs may be able to help alleviate problems in connection with
the recent increase in (childhood) obesity [11] and a potential increase in attention problems [12], training
EFs is the primary outcome of the current project. Our intervention is built around the idea that EFs are
the core drive behind a myriad of essential capacities and skills in life (self-control, attention, emotion-
regulation; which in turn help an individual govern his/her behavior toward healthy behaviors such as
physical activity and healthy eating)[9]. Hence, we focus most of our attention in this paper on EFs; what
they are and why they are important, how they are best trained and how our intervention was designed to
meet the most recent recommendations in the field.
Executive Functions

Executive functions (EFs) comprise three top-down, interrelated core mental skills: (1) inhibitory control (IC), (2) working memory (WM), and (3) cognitive flexibility (CF) [13]. Together, they enable us to plan, reason, and solve problems [9]. These processes are also used when relying on automatic behaviors is ill-advised or counterproductive, for example, longer-term personal goals. EFs are interrelated in the sense that WM and IC generally need one another and co-occur, and CF builds upon these two processes [9].

Inhibitory control

Inhibitory control involves being able to control one’s attention, behavior, thoughts, and/or emotions [9]. One might feel the urge to indulge in a delicious cone of ice cream, but impulse control (an aspect of inhibitory control and a major prerequisite of self-control) can override such automatic lure, in light of one’s goal to consume fewer calories [7]. The inability to resist temptation and think long-term underlies various automatic behaviors that are potentially harmful to physical well-being.

Working memory

Working memory involves holding information in mind and mentally working with it [9]. We need working memory to make sense of the world around us (e.g., follow and understand spoken or written language), to reason and to connect seemingly unrelated ideas [9]. Additionally, WM is vital for processing/understanding new information and remembering personal goals and intentions, which is definitively useful in the context of physical activity and healthy eating.

Cognitive flexibility

Cognitive flexibility includes being able to see things from different perspectives, creatively think “outside the box”, and quickly and flexibly adapt cognitive processes to changing circumstances [9]. Depending on your cognitive flexibility or rigidity, it may be easier or harder to recalibrate your thinking processes to make use of newly arisen possibilities and adapt to new, more efficient technology, or revise certain beliefs or attitudes when presented with new information (which is the case in our eHealth module).

EFs and Academic Achievement/Performance
It is generally assumed that stronger EFs lead to improved academic achievement [3]. EFs appear to be moderately and positively correlated with academic achievement (around 0.30 for all age groups from 5-10118 years old), according to the most recent meta-analysis [14]. However, upon closer inspection, the evidence regarding a causal relationship between the two is not so equivocal or compelling [14]. In the aforementioned meta-analysis, the authors argue that interventions targeting both EFs and academic achievement (math, reading) simultaneously and directly, are not able to establish a causal relationship. The Chicago School Readiness Program [15] is an example of such a program. Nonetheless, these kinds of studies do provide substantial evidence for the malleability of EFs (for example, following a school-based intervention), as well as the potential to improve academic achievement [14]. Alongside the importance of a solid RCT, the establishment of a working definition of EF, and the rigorous categorization of EF measures according to that definition, is warranted [14]. TyM attempted to demonstrate that academic performance improvement is mediated by EFs. In our design, we have taken into account past recommendations and findings. It is worth noting that TyM does incorporate some basic math and language exercises (the adapted Memory game), and in this sense, can be seen as addressing EFs and academic performance simultaneously.

**EFs and Cognitive Development**

Developmental studies reveal that all three EF core skills are still maturing in our age group of interest (9-11-year-olds)[16, 17], which allows for more malleability and thus additional training [18]. We targeted each of these sub-components (WM, IC, & CF) individually in both our training and our measurements. That is, we selected training games and measurement tasks specifically matched to each sub-component. However, due to the strong interrelated nature of these three EF core skills, they are often taxed and trained together. This is not a limitation per se, as it has also been suggested that EFs are most successfully trained when multiple core skills are engaged simultaneously, and differences on outcome measures become most apparent when the task is challenging [9, 19]. TyM targeted regular class groups, and is as preventative in nature, minimizing various risks and challenges to be overcome later in adolescent life and beyond. Simultaneously, some children in these regular school classes may be lagging behind in EF
development, and it has been proposed by several authors that these individuals may benefit more from EF training and catch up with their peers [9].

**EFs, Health, & Quality of Life**

The strength and endurance of EFs can be trained in order to boost their natural development [2]. This is especially interesting given the wide range of long-term correlates found for EFs, in terms of both physical and mental well-being [8]. Fostering the development of executive functions at a young age equips children to deal with many challenges in life. During the adolescent years, there is a developmental mismatch between the cognitive control system and the social-emotionally sensitive reward system [20], leaving youngsters vulnerable to potentially detrimental behaviors such as risky car driving, unsafe sex, and experimenting with substances [21]. More seemingly unremarkable behaviors -- such as sedentary behavior (e.g., screen time) and a high caloric diet -- can have equally detrimental consequences in the long run [22]. Here too, EFs are at the core of the problem (relatively weak EFs) and, simultaneously, the solution (strengthened EFs). Avoiding or limiting risks is only one part of the story. The positive counterpart to this is to improve what is already working well. Effortful control cannot prevail constantly; in fact, much of our daily behavior is automatic and not governed by EFs. Habits are omnipresent in everyday life, and EFs can play a role in both shaping and strengthening healthy habits (consciously thinking about and planning new or adjusted behaviors) and weakening or breaking bad habits (refraining from relying on impulses and urges). After a while, the new habits will override the old ones and eventually replace them, at which point there is no longer need for effortful control.

The prefrontal cortex can serve as a gatekeeper for the dopaminergic reward-learning mechanisms, enabling us to override lower-level activity (e.g., impulses). Overriding impulses in such a consistent, systematic way often is at the heart of health promotion. This mechanism is explained by the prefrontal-cortex basal-ganglia working memory model [23]. According to this model, after a while, it will become easier for the individual to adhere to positive behaviors as these behaviors are constantly being reinforced (while the connections associated with negative behavior lose power). Such positive reinforcement combined with an increase in absolute EF capacity, offers promising avenues for health-promoting
behavior change programs. Stronger EFs can amplify the learning process, while weaker EFs can do the opposite. Interventions aiming to change behavior could therefore benefit greatly from including EF training. Our intervention follows this line of reasoning as three modules aim to enhance EFs, while the additional eHealth module targets behavior change directly.

The potential economic gains for a nation as a result of combined increased health are substantial; for example, it has been estimated that healthy eating could save the United States $119 billion per year [24]. The essence of an EF-intervention can eloquently be summarized as ‘disciplining the mind in the art of staying focused’ [9]. In summary, EFs can be trained, and elevated levels of EFs will allow the individual to avail him- or herself more fully of the potential that is present in the brain structures that make us so uniquely human. Being able to learn new things more effectively (academic performance), control oneself adequately, regulate emotions composedly, and cope well with challenging temptations or difficulties, can contribute to a richer life in various domains.

Consequences of Poor EFs

One clear example of how executive functioning can result in negative consequences can be found in the domain of inhibitory control. Behavioral disinhibition (i.e., malfunctioning self-control), refers to an individual being unable to inhibit his or her pre-potent, dominant response. The individual is unable to refrain from performing an action, even when it is fairly obvious that detrimental consequences will follow, not only in the long-term, but also in the immediate short-term. Better EF ability appears to be associated with fewer of the following behavioral problems: conduct disorder, attention deficits, substance abuse, and novelty seeking/risk taking [25]. It is not only inhibitory control that has been found to be linked to certain undesirable behaviors; similar relationships have been found for task switching (cognitive flexibility) and updating (working memory). Other examples of such self-regulatory behaviors related to EF include staying faithful to romantic partners [26] and the expression and control of implicit racial biases and prejudice [27]. Moreover, EFs have been found to moderate the association between behavioral intentions and behavioral performance --more specifically, physical activity and dietary habits [28].

EFs & Emotion-Regulation
Inadequate emotional regulation is linked to various problems in childhood and beyond, including psychopathology, obesity, and addiction [29]. On the other hand, adaptive emotion-regulation is associated with higher quality of life, well-being, and healthy interpersonal relationships [30]. There is an overlap in the main neural mechanisms involved in both emotion-regulation and EFs, more specifically the prefrontal structures of the brain and the pathways from these areas to limbic structures such as the amygdala [31]. This overlap promotes the idea that they are related processes with a binding link. Several studies have investigated the positive relationship between EFs and emotion-regulation [32]. The evaluation of stimulus information and the generation of one's own response requires WM updating, as well as inhibiting (IC) a pre-potent emotional response and being able to switch attention (CF) from the stimulus to one's own emotional response [33]. As such, maturing EFs may contribute to and facilitate the ongoing development of emotional regulation. The development of both, then, has a top-down effect on one's emotions, behaviors, and thoughts, and one's ability to regulate them [34]. These insights led us to include emotional-regulation in our intervention.

Effortful control is considered one of children's temperament characteristics, besides negative emotionality (anger/frustration) [35]. Such temperament characteristics are measured in early childhood at 3-4 years of age, mostly by parent and teacher questionnaires. EFs know a more extended development across childhood and adolescence, and are sensitive to training [3, 16, 36, 37]. There are reports in the developmental literature of inverse links between (bottom-up) temperamental reactivity (amongst which lack of effortful control) and the quality of subsequent development of executive (top-down) control mechanisms (inhibition and working memory) in later childhood as measured and trained in the present study (but most of these studies are cross-sectional and not longitudinal in nature) [35]. However, since we included children between 9-11 years and this is not a longitudinal study, we did not measure temperament (we consider retrospective measurement of early childhood temperament of the children to not be reliable). Furthermore, we are of the opinion that knowledge of children's childhood temperament is not pertinent to answering the current research questions about the effectiveness of the intervention to improve EFs and healthy behaviors. Theoretically, training of executive control would enhance top-down control (inhibition/working memory/flexibility) and would, as mentioned before, enable children to have
more control on bottom-up urges resulting from temperamental characteristics (for instance being better
able to inhibit/resist automatic tendencies (temperamental characteristic of negative emotionality) to
react to events with negative emotionality or thoughts. Another example would be that the development
of increased working memory capacity might provide children with the mental space to contemplate and
reason about consequences of their actions, perhaps preventing impulsive actions steered by individual
differences in temperament.

Methods

Intervention Mapping

The ‘Intervention Mapping’ protocol (IM) guided us in developing precisely such an integrated
intervention with wide-spread outcome expectancies. At this juncture, it is important to note that we did
not apply IM in a strict sense, since the nature of EF-training does not allow for in-depth IM-techniques
(the performance objectives can be summarized as (a) adhere to the intervention, for children, and (b)
deliver the intervention, for teachers). Once the teachers are convinced of the potential of TyM, and agree
to participate, the children will automatically take part in the intervention as it is integrated in the existing
school curriculum. As such, there are no change objectives for ‘adhering to the intervention’. Nonetheless,
children’s enjoyment and motivation are crucial, and every component tries to maximize and maintain
these factors (through ‘parameters for use’). Different to the core of EF-training, is the online behavior
change module (‘eHealth’); here, determinants are targeted and changed. The change objectives are
reflected in the personalized feedback (e.g., “Ask your mother or father if you can choose a vegetable that
appealing to you in the supermarket”). As the IM authors state, the IM steps and tasks are not “the
letter of the law”[10]. Rather, IM served as an underlying, more abstract reasoning framework, which
guided us to follow major IM steps (needs assessment, outcomes & objectives, methods & applications,
program implementation, and evaluation). Performance objectives for, for example, the Socio-Emotional
Learning module of TyM are not explicitly addressed in the current paper, as the scale of our project
designing multi-module intervention and testing in an RCT) did not allow IM to be applied at full length
for every component. These performance objectives are integrated in the existing programs
demonstrated to be effective][38, 39] on which we had to rely as a basis for our modules, and subsequently incorporated in the TyM manual/intervention protocol for teachers. The IM protocol [10] describes the iterative path from problem identification to problem solving or mitigation. The first step in the IM protocol is to conduct a needs assessment -- or problem analysis -- by identifying what, if anything, needs to be changed, and for whom. In the current study, we were interested in the potential benefits gained from enhanced EFs in a normal population of 9- to 11-year-old children. In IM step 2, the specific objectives of the proposed intervention are defined. The following IM steps 3 and 4 involve devising a theory- and evidence-based intervention that can stimulate EF development. Planning the implementation of that intervention by the teachers takes place in IM step 5. Finally, in IM step 6, careful consideration is given to process and effect evaluation.

**Results**

**Step 1: Needs Assessment**

The correlation between EFs and various health-related outcomes (ranging from obesity and bullying to substance abuse and unsafe sex) appears to be substantial. Moreover, quality of life in a broader sense is also related to EFs; increased EFs are associated with better social relations, self-control, and academic performance (concentration, attention, math and reading skills). Although a causal relationship between strengthened EFs and improved health has yet to be fully demonstrated, we do know that EFs are trainable; hence our attempt at training them and effectuating broad transfer effects (cognitive/academic and socio-emotional development, physical activity, and healthy eating). In summary, TyM is both preventative (in terms of minimizing risks and unhealthy behaviors), as well as promoting (fostering healthy behaviors).

**EF within the Socio-Ecological Model**

The Socio-Ecological Model [40] postulates individuals are influenced by several environmental levels, and forms an important part of understanding behavior within IM. How do the different environments, in which a child grows up, affect the development of EFs? A child will do most active learning in the class room, which arguably makes this the most important level. What teaching style does the teacher employ?
What is the child’s daily schedule, what tasks are given, how is the classroom set up? Structure and order help a child develop his/her EFs more easily, as well as the actual (academic) tasks that are performed. Classmates and peers also play a role; how does the child deal with tension or bullying, what is the social atmosphere like in school? Although all these factors are relevant, it was outside the scope of TyM to deal with them all. TyM’s socio-emotional development module addresses emotion-regulation and how to deal with certain social situations. It is important to keep in mind that EFs affect, and are affected by: stress, social connectedness, sleep, physical fitness, and mood. Breathing exercises offer a technique to deal with stress, another goal of the socio-emotional development module is to increase social connectedness and competence (for example by talking about others’ feelings and how people can perceive the same situation differently). Strengthened EFs will facilitate adherence to healthy behaviors; in our project physical activity and healthy eating – behaviors which are also targeted additionally through personalized feedback in the eHealth module of TyM. EFs benefit greatly from a healthy lifestyle. Other socio-ecological levels include parents, sports clubs, and society, but these were out of reach for the current intervention.

Step 2: Objectives of the Intervention Train your Mind (TyM)

EFs can be trained from a very early age (as early as 4 years of age)[9]. TyM focused on children between 9 and 11 years old. We chose this age range for two reasons: (a) it is the stage right before adolescence, and training EFs may help to prepare children for this turbulent developmental stage, with all its tempting risks, and (b) there is more flexibility in terms of what components can be used to address cognitive- and socio-emotional development for children of this age, as compared to younger children [18, 41]. Additionally, neural plasticity is high throughout childhood, which allows for the effective training of brain networks underlying EFs and related cognitive and socio-emotional development [42].

Our primary objective was to instigate the development of EFs; this in itself is not an observable behavior as such, and can only be measured by a combination of tests. The secondary objective of this project was to foster several observable behaviors that are related to EFs. These secondary outcomes include academic performance, concentration, emotion-regulation, physical activity, fruit and vegetable consumption, and avoidance of sugary beverages and unhealthy snacks. In terms of ‘Intervention
Mapping’ (IM), the aim of the current study differed from that of other studies in that the main focus was on promoting EFs and not on changing behavior (aside from the eHealth module).

Steps 3 & 4: Methods, Applications, and Program: Train your Mind

In accordance with Diamond’s [2, 3, 19] most recent suggestions regarding how EFs can be improved, the current intervention was originally developed with three particular components in mind: (1) focused physical exercise, (2) cognitive training, and (3) socio-emotional development. However, a fourth component, (4) eHealth, was added to specifically and directly target the following healthy behaviors: (a) physical activity, (b) fruit & vegetable consumption, and (c) decreased consumption of unhealthy snacks and sugary beverages.

We designed our ‘Train your Mind’ (TyM) intervention in such a way that, in the long term, it can be delivered by teachers, independently from any other institution (but supported by an online platform). Ideally, once the program has been fine-tuned, TyM can be used cost-effectively (i.e., without much support from third parties) by various elementary schools. However, during the current TyM RCT, an elaborate feedback-loop between implementers (teachers, schools) and developers (our research project group) was warranted. During the development of our intervention, we tried to identify the most practical, effective, and enjoyable form of TyM. Teachers and children helped shape the content of TyM during pilot-testing, and this process continued for the duration of the actual RCT, aiming to result in a polished version of TyM that can be delivered in many more schools in the future. On hindsight, it would have been very helpful to include educational experts with a background in EF in this planning group of teachers (and children).

Module 1: Focused Physical Exercise

Although aerobic exercise has been shown to boost EFs, the effects are small and short-lived [3, 43]. It has recently been acknowledged that, in order to train EFs in a sustainable manner over a longer period of time, mind and body have to be simultaneously engaged [3, 43]. The two work synergistically, in balance. Thus far, only taekwondo [44, 45] and yoga [46] have been shown to improve EF in such a sustainable manner. These traditions stem from the Far East, home of another ancient martial art that embodies the...
theory behind our sustainable mind-body connection -- kung fu. Kung fu literally means grand skill, great
collection, and pure dedication. It is the art of learning discipline and respect, of practicing a skill with
endless patience. It has nothing to do with competition or with being superior to others. This underlying
philosophy resonates with what we want to teach children, and what EFs stand for (concentration,
discipline, practice). To explore this connection further, we collaborated with a kung fu expert (i.e., sifu)
with more than 40 years of experience that includes teaching children. We conducted a pilot-study in
which three schools participated (two experimental, one control) with one group each (n=63) receiving six
kung fu sessions during regular physical education classes over a course of five weeks, from the sifu
himself. The data of this small pilot study show that the experiences of both children and teachers were
positive; everyone was curious, open-minded and motivated to engage and to learn.

In order to facilitate the implementation of this focused physical exercise component in the upcoming TyM
RCT, we organized workshops in which teachers were taught how to use simple kung fu exercises in their
own class during physical education, by the kung fu sifu himself. He held an initial training session with
every intervention group at the beginning of the program, and a second session a few months into the
intervention in order to rehearse these exercises and provide further guidance. During these sessions, the
teachers gained first-hand experience of how a kung fu sifu handles their class. Furthermore, a manual
was available to the teachers, created by the kung fu sifu and comprising a series of lessons broken down
into simple exercises. Background information and pictures of movements and posture were included in
this manual. A total of 25 kung fu sessions was given to every intervention group over the course of 25
weeks, with one kung fu class taking the place of one traditional physical education session every week.

Module 2: Cognitive Training

Many efforts have been made to enhance EFs through cognitive training [3, 9]. Working Memory (WM)
in particular, has been the focus of much attention in the past decade. CogMed®, a computerized WM
training program, has been demonstrated to effectively train WM, and in several studies, transfer to
cognitive tasks unrelated to WM -- or to the training -- has been found [47]. Furthermore, transfer to
reasoning tasks has also been reported, substantiating the notion that fluid intelligence (Gf) can be
enhanced, even more so when training is repeated and adaptive [48]. However, one extensive study that tried to put these findings to the test with 11,430 healthy participants found no evidence of transfer effects [49] – except for improvement on the training tasks. Six weeks of unsupervised sessions (a minimum of 10 minutes a day, three days/week, total minimum of three hours) may not have been enough to effectuate transfer to other tasks. However, one previous study in which transfer to unrelated cognitive tasks was found [48], had a similar amount of 8 to 19 sessions of 25 minutes, averaging three hours in total, albeit supervised. This may once more point to the crucial role that implementation plays in the effectiveness of a program. Our aim, therefore, was to include as much supervision as (practically and realistically) possible for the participating teachers. It has been shown that children’s (7-9 years old) reasoning (fluid intelligence) was improved in an 18-hour total training program consisting of both computerized and interactive games [50]. Computerized task-switching games have also been shown to foster the transfer of relatively general executive control abilities in children aged 8 to 10 [51]. In the latter study, variable training hindered this transfer in children – but this might have been due to complicated tasks putting a strain on limited WM capacity [51]. On the other hand, tasks should be progressively challenging in order to keep individuals motivated and encourage them to maintain growth – as in adaptive training. Broader transfer is more likely to be obtained if EFs are addressed more globally, as is the case in task-switching training [51] and yoga [46]. Certain school-curricula adopt a similar global approach, which will be discussed in the section ‘Socio-Emotional Development’. A fine balance between the challenge and the number of core EFs involved is required; training games should tap into multiple EF sub-components simultaneously (as is the case in our individual online cognitive module, Cambridge Brain Sciences – which is described more elaborately in the designated paragraph later in this article, but not in CogMed®, which mainly taxes one EF sub-component at a time), but remain at the right difficulty level for the child. This need for an individual, adaptive, incremental difficulty level was the main reason for the online component of cognitive training in our intervention TyM. The simplest principle is perhaps also the most important of all; EF improvement is highly correlated with practice time [3]. These aforementioned training principles (multiple EFs simultaneously, complex EFs, incremental difficulty level, sufficient practice time) are in essence identical to IM’s parameters for use. In order to minimize additional time
spent on TyM for the teachers, cognitive games were mainly played in groups (1h/w), supplemented with short on-line sessions (2 x 15min./w). The most compelling argument for collective games, however, stems from promising school-curricula add-ons such as ‘Promoting Alternative Thinking Strategies’ [52], the ‘Chicago School Readiness Project’ [15], and Diamond’s suggestion that children’s social, emotional, and character development should also be addressed in EF training programs [19]. Our third TyM component, Socio-Emotional Development, aimed to do precisely this. Meanwhile, it should be noted that many of the socio-emotional benefits gained from this component are also associated with playing board games. They go hand in hand. While playing board games, children have to organize fair groups and follow procedures, get along while competing, cope with losing, etc. As such, social competence, a vital ability in a person’s life [53], is trained alongside EFs. We took all of these factors into consideration when selecting and developing various games for inclusion in our intervention. Concluding, while individual cognitive games, on their own, may not hold strong enough to yield broad transfer effects (which is why we embedded this individual component in a larger integrated multi-module intervention), we believed they would still play a valuable role in combination with complementary components. We argue that, in a sense, part of the EF development would be done by individual games, and then picked up and continued by other modules. Furthermore, incrementally challenging individual levels and (subsequent) motivation are strong factors in the EF development equation, provided by said individual games.

Collective Board/Card Games

The board/card games within TyM consisted of: (a) SET, (b) Memory, (c) Taboo, and (d) Charades. These games were played in groups in class, for a total of one hour per week. To target EFs in the context of academic tasks, we attempted to include relevant study material by incorporating Memory (mathematical calculations, fractions, clock-reading, and antonyms) and Taboo (vocabulary, synonyms, and antonyms). All games were pilot-tested extensively and selected accordingly (concept-testing; are the games suitable for our age group, and which ones are liked best?). These board games vary in the extent to which EFs are tapped into/stimulated, but most tasks clearly address all EFs in some way.
SET is a commercial board game that resembles the Wisconsin Card Sorting Task and strongly relies on shifting (CF) and updating (WM), though impulse control (IC) is also needed. The objective is to find sets of three cards on which the images depicted are either all different or all the same in terms of four categories (color, shape, filling, and number). Speed and flexibility are important as everyone looks for sets simultaneously. Multiple strategies are possible, but the board is constantly changing, which calls for quick adaptation and flexible thinking. In order to play the game, considerable information must be held and manipulated in the mental workspace (WM), as children mentally test out and complete various combinations of cards, trying to find a SET that meets the criteria (also to be held in WM). The player finding a set may keep those cards as they represent points (one set equals three cards or three points).

The player to first say 'set', may indicate the presumed set and take it after quick validation by other players. However, saying 'set' too quickly (without being able to actually indicate a set) will result in losing one point (one card). Inhibition/IC is required to avoid this possibility, as well as not getting too distracted or frustrated by irrelevant thoughts and emotions. During pilot-testing, SET was given the highest rating by both teachers and children.

The classic game of Memory was modified for TyM. In this game, two groups of cards are laid out together, face down, in opposing rectangles – one consisting of exercises/problems, and the other of solutions. A child picks a card with a mathematical task/problem, and then tries to find the solution in the other group of cards. While updating a visuo-spatial map of stimuli, a mathematical calculation is also processed – it is reasoned that this interplay between EF sub-components (updating and shifting) increases the effectiveness of the training. The same applies to clock-reading (analog and digital clocks) and antonyms (e.g., water and fire).

Taboo requires verbal creativity, as in this game the child has to explain a given word verbally, but without using four key words that accompany the exercise word on a card. These key words are often the first words that come to mind (e.g., animal, pet, bark, loyal for the word dog) and therefore need to be inhibited. Players must then find alternative ways of explaining the word to fellow players, whose task is to guess that word. For example, a liquid substance that falls from the atmosphere, plants drink it (rain – water, cloud, wet, umbrella). Usage of synonyms and antonyms can help.
In the game, Charades, the child must act out certain words or concepts without using any sounds. His or her teammates try to guess what the word/concept is. Words are either generated by the opposing team (categories may include: movies, animals, countries), or given by the teacher (which facilitates the learning of new relevant vocabulary). Charades fosters more artistic expression than the other, more cognitive games – and is therefore a welcome addition to the game pack for children who do not find math and language so enjoyable. The game addresses all three core EFs (CF, IC, & WM), as the child is required to keep track of the mental directions in which his or her guessing teammates are searching. Moreover, he/she must adapt/switch his or her behavior accordingly, suppressing earlier plans and substituting them with new ones. In this game, the child must follow the thinking of his/her teammates, and, if it is in a hopelessly wrong direction, be able to communicate this non-verbally and get them back on the right track. Updating wrong guesses (WM) is also helpful. Both Taboo and Charades are played against time.

The content of these games was adapted to existing learning materials (math level, vocabulary), in an effort to integrate the intervention as much as possible into the existing school-curriculum. All these games can be played competitively, although it is up to the teacher to handle this with care. The main objectives to be encouraged are progress, learning and fun, although social comparison is almost inevitable and not necessarily a bad thing [54]. A healthy competitive spirit while playing games can help keep children motivated to try their best. However, when differences between children are too pronounced (e.g., in math ability), it is better for them to play in groups of a comparable level. Our observations during pilot-testing suggest that children who are a little slower in one domain (e.g., Math Memory), usually display strength in other domains (e.g., Charades). Ideally, the teacher -- who knows his/her pupils well -- will keep an eye on proceedings and help maintain a positive atmosphere. Creative adaptations by the teacher, tailored to a specific group in order to increase gameplay, are encouraged. Scientific purity (i.e. that everyone does exactly the same) is sometimes sacrificed in order to increase practical feasibility and motivation. Similarly, while games are supposed to be played for a total of one hour each week, teachers are free to organize this to best fit their own particular schedule. TyM
encompasses multiple components and can be rather intensive for a teacher, which is why a certain degree of flexibility is warranted. The manual and several cognitive group games are shown in Figure 1.

Figure 1: The TyM manual and several cognitive group games.

Individual Online Games

EF training is more effective when participants are progressively challenged at an individual level [47, 48, 49-56]. Cambridge Brain Sciences (CBS) is an online platform that offers many tests, or games, well suited for both training (despite limited transfer) and measuring EFs within the particular age group of our interest [49, 56]. Despite the apparent lack of transfer found through cognitive training alone, this component was included in our TyM intervention. The reasoning behind this is that, in combination with other approaches, cognitive training may very well serve the purpose of strengthening overall EFs, and, eventually, help in achieving much-desired transfer. Additionally, CBS games are more complex and engage multiple EFs simultaneously, compared to more traditional cognitive training, which is suggested to increase the likelihood of broad transfer to occur [3]. Such broad transfer training effects have of yet not been demonstrated by CBS, nor CogMed® or any other cognitive program. In collaboration with CBS, we set up our own TyM trial consisting of five games: (a) Stroop, (b) adapted Raven’s Progressive Matrices, (c) paired-associate-learning, (d) Hampshire Tree Task, and (e) Spatial WM/planning. These games were to be played twice a week for 15 minutes, in a varying order of sequence. Every child could see his/her individual progress on a visual plot. Comparison to the entire population that has ever played CBS (all ages), was turned off in order to avoid discouragement. The CBS tasks are generated using sets of complex algorithms, which make the problems presented during the tasks unique, and also allows for training purposes. Every time a problem is solved, the level increases – while it decreases when an error is made. After an initial period of training, the children are able to skip through the easier levels quickly and play at their own level. The lowest levels are relatively easy and the incremental increase in difficulty is practically endless: a game is therefore never too difficult or too easy. This procedure is in accordance with the parameters for use of online cognitive training.
In recent reviews, it has been suggested that a socio-emotional component might be the missing link in EF-training \cite{2, 3, 19}. Considering the multitude of factors that have been found to be related to EFs, one might indeed suspect that it takes more than mere cognitive games and focused physical exercise to enhance EFs. These socio-emotional factors include social connectedness, stress, mood, and self-regulation, which in turn includes attention-regulation and emotion-regulation \cite{9}. Note that all these relationships are bidirectional in nature: e.g., EFs will flourish in a positive, supportive social environment, and, vice versa, empathetic, self-composed (high EF) individuals will contribute to creating a more positive environment. In other words, EFs both influence, and are influenced by, the aforementioned factors.

Indeed, EFs and self-regulation have been found to predict children's social-emotional competence and academic performance \cite{19}, altruistic behavior \cite{57}, and long-term life success. This bidirectional relationship can also be negative; a bad mood can hinder executive functioning, while poor EFs can negatively influence mood \cite{9}. Considering the lack of broad transfer in more straight-forward EF-training programs with a relatively narrow focus, we opted to approach matters with a multi-component intervention.

Social-Emotional Learning (SEL) programs focus on promoting self-awareness, self-management, relationship skills, and responsible decision making \cite{58}, and have shown success in improving top-down cognition and social-emotional competencies \cite{38}. Merging SEL with mindfulness allows SEL to be taught in a practical rather than a conceptual way, as children can experience for themselves what emotional regulation feels like through mindful awareness and breathing exercises. An example of this kind of approach is the MindUp program \cite{39}. MindUp targets both top-down cognition through lessons, as well as bottom-up modulation via breathing and auditory (mindfulness) exercises. Such breathing exercises correspond with the IM method 'improving physical and emotional states' (prompting interpretation of physiological and affective states), to change skills and capabilities (e.g., recognizing that the physical arousal prior to a presentation is mere excitement, and deep breathing to relax). Promising results for the MindUp intervention \cite{39} were found in one recent study of 9- to 11-year-olds which reported improved cognitive control, empathy, perspective-taking, and emotional control, and decreased self-reported
symptoms of depression and peer-rated aggression [59]. The MindUp program served as the basis for our own, adapted, Dutch SEL program, supplemented by exercises and insights from a practitioner’s guide on emotion-regulation among children and adolescents [60]. As the TyM SEL module is built from the fundamentals of SEL [58] and MindUp [39], both of which have shown to improve social-emotional competencies, these competencies should also be fostered in TyM. Considering the magnitude of the current TyM project (designing intervention and testing in an RCT), we were not able to apply IM at full length (performance objectives, matrices). Rather, we had to rely on existing programs that have already garnered empirical evidence [38, 39]. Performance objectives as such, are integrated in the existing programs for both teachers and children, but are not explicitly mentioned in this paper. The TyM SEL program consisted of 11 lessons, given during the weekly half hour dedicated to this component in the overall TyM intervention, over a period of 25 weeks (excluding holidays). Workshops were organized in order to introduce the SEL program to teachers, as they were to deliver this component to the children. A manual with exercises and background information was available to assist the teachers. This component of the intervention was easily integrated as all schools already had such a ‘socio-emotional half hour’ every week.

**Module 4: eHealth: Tailored Feedback**

To further reinforce the bridge between enhanced executive functions and our ultimate behavioral outcomes, we sought to implement a cost-effective tool that is easy to use in schools. eHealth offer such a platform, and has been found to foster health-promoting behaviors, including physical activity and healthy eating, among both children and adolescents [61, 62]. This approach incorporates behavioral methods such as goal-setting, self-monitoring, and immediate feedback. We identified five key health-promoting behaviors for our own eHealth module: increased (a) physical activity, (b) fruit- and (c) vegetable consumption, and decreased intake of (d) sugary beverages and (e) unhealthy snacks. These topics were distributed over six sessions, with three weeks in between each session. Previous effective interventions with similar topics and target populations, varied in their ICT contacts from twice a day to once every 12 weeks, to even one contact in total [63]. Our timing of deliverance is situated somewhere in the middle, allowing children time to take in every topic, try out recommendations and hopefully form new healthy habits.
habits. From an organizational, pragmatic point of view; our frequency could not be too fast as we needed
every participating school group to have finished a topic, before the next one could be made available on
the on-line eHealth program – to ensure a certain level of homogeneity of our intervention delivered. In
the first session, each behavior was measured via self-report (this served as the baseline), alongside
various psycho-social determinants of physical activity. The other behaviors or topics were then addressed
one-by-one in the following sessions. A session typically consisted of a small self-report measure of the
behavior – on which feedback was given in accordance with national recommendations. Next, psycho-
social determinants crucial to behavior change were assessed and personalized advice was given in
relation to these. Every session concluded with action- and coping-plans, and the child was encouraged to
write these down and follow through on them. These are the behavioral methods mentioned earlier. The
psycho-social determinants we selected in our eHealth module include (a) knowledge, (b) attitude, (c)
perceived norms, and (d) self-efficacy – inspired by the I-change model [64] that integrates elements of
social learning theory [65], the transtheoretical model [66], the health belief model [67]; the theory of
planned behavior [68], the reasoned action approach [69] and goal setting theory [70, 71]. Personalized
advice was given along the lines of these psycho-social determinants, in an effort to change behavior.
Based on the responses of children given, for example, in relation to the advantages of physical activity,
they received feedback reinforcing the positive beliefs they already had, and also providing new
information regarding other beliefs where misconceptions could occur. For example, possible positive
attitudes one could -- but did not yet, have -- were highlighted (e.g., physical activity is fun, healthy, good
for growing, and makes you sleep better). Similarly, based on the child's responses with regard to his or
her social support, personalized feedback was given on how to make use of his/her social network/norms
(e.g., "ask a friend to play a new game (exercise/sport) you both might like, right after school"). Depending
on the level of self-efficacy of the child, coping plans (how to deal with difficult situations) were given or
devised by the child him/herself. When a child had low self-efficacy, more attention was paid to coping
plans. These coping plans were combined with personalized suggestions for developing preparatory plans
to increase a certain behavior (e.g., "I will ask a friend in the neighborhood to play outside instead of
playing on my tablet when I get home from school before dinner time" – when the child had identified
that situation as tough to be physically active in). In the last session, feedback was given on the ‘developmental path’ of each behavior – was a child more physically active in comparison with the baseline? The entire eHealth module was then concluded with a certificate (see Figure 2) that could be printed, signed and hung up at home. On this certificate, three final, take-away, personally chosen action plans were highlighted. For example, “I will take a handful of grapes to school to eat when I’m hungry instead of a candy bar”. Bearing both our target-population (9-11-year-olds) and lack of resources for extensive use of video or animation in mind, we embedded the TyM eHealth program in a colorful jungle graphic environment, with basic text-balloon messages delivered by a toucan and a leopard. Pilot-testing among children of varying age and reading proficiency resulted in almost exclusively positive feedback about the design (indicating that the program is "interesting", “fun", and has “beautiful drawings”).

Figure 2: Example of the eHealth certificate with three personally chosen goals. Graphic design by Jessica Mayer Koren.

Step 5: Implementation Plan

Train your Mind (TyM) could be integrated into the school curriculum and delivered independently by teachers. Time is generally a valuable commodity among teachers. In order to optimize both (feasible) implementation and motivation, it was absolutely pivotal that the materials were time-efficient and easy to use. We pilot-tested all our materials and collaborated with a partner-school to explore the feasibility of our activities and learn from experienced teachers how certain games could best be implemented. We allowed for quite some flexibility in terms of structure; teachers had the freedom to decide when to do what – as long as the time-investment goals of the training were met (e.g., 1h of collective cognitive training per week). During workshops, the materials were fully explained and examples of gameplay or activities were given. However, teachers carried tremendous responsibility as they alone delivered the program to the children. It was therefore imperative that we made their job within TyM as easy as possible. The research team was mainly responsible for designing materials, organizing workshops, compiling a practical manual for the entire intervention, constructing digital platforms, and offering...
support wherever needed. Although everything had been pilot-tested, it would be the first time that most of the materials and approaches were used in this context, meaning that close contact should be maintained between the intervention development team and the teachers (in IM terms: participation).

Through feedback loops (individually and collectively), program components could be adjusted or updated along the way. This was also important in terms of sustaining levels of motivation among both teachers and children. Dosage -- how much of what is done when – is to be recorded in the manual. The amount of assigned lessons/sessions that were actually given, over the total amount that should have been given, is also to be recorded throughout the intervention by the teachers in the TyM manual, and summarized in the IM variable ‘completeness’. Evaluation is to take place throughout the intervention (collectively after the first two months and individually later on), and formally at the end of the intervention, after 25 weeks (excluding holidays). This evaluation will be carried out using a questionnaire comprised of quantitative (scoring) items as well as open-ended questions, and an interview. The interview will concern how the intervention generally went but also to what degree teachers stuck to the original lessons/instructions.

Note that this last item corresponds with the IM variable ‘fidelity’: the extent to which the intervention is delivered as intended. Completeness (or dose delivered) is more quantitative, the amount of intended units of each program component that is delivered, and measured by the teachers in a schedule/agenda in the TyM manual (for the online components we will be able to verify this ourselves, digitally). Fidelity is more qualitative, and measured by observer ratings but partly also by self-report and interviews (e.g., were crucial sub-components of modules delivered each time?). In terms of IM; the sole main performance objective for the teachers during TyM is to deliver the intervention. Key determinants of this task are speculated to be self-efficacy/skills (i.e., how confident are they that they can deliver it; this means instructions have to be very clear, and the barrier of time needs to be dealt with accordingly) and attitude (do they think TyM is effective and fun; experiential experience offers the strongest argument here; if they can see the children having fun and perhaps even noticing improvements in attention or behavior, their attitude will grow more positive and they are more likely to adopt TyM long-term). Further down the road, we may even be able to incorporate EF training into the formal training of teachers – for which other IM environmental agents and stakeholders need to be convinced.
Step 6: Study Design – Evaluation Plan

The effectiveness of Train your Mind (TyM) will be investigated in a Cluster Randomized Trial comprising 13 elementary schools, with a total of 34 groups and 800 children. The design for this RCT, with special attention to the outcome measures, as they are so vitally important in EF research, is described in great detail in a separate paper. It is important to note that the primary outcomes, EFs, will be measured using computer tasks that are different to the intervention (training) tasks, as to ensure avoiding measuring training effects. The secondary outcomes, as mentioned in step 2, entail: academic performance, concentration, emotion-regulation, physical activity, fruit and vegetable consumption, and avoidance of sugary beverages and unhealthy snacks.

Discussion

The present paper describes the need for -- and the development of -- an intervention designed to enhance executive functions (EFs). Executive functions appear to be paramount to a healthy and happy life [8, 9]. The list of long-term correlates (e.g., physical and mental health, income, marital success [8]) and proximate (short-term) resonating factors (e.g., mood, connectedness, sleep, physical fitness [9]) is astounding. It seems that EFs influence, and are influenced by, a plethora of elements vital to quality of life. Given the importance and trainability of EFs, much effort has been directed at connecting these correlates to increased EF [2]. To this day, studies have reported limited success [3]. Our approach is novel in the sense that, following recommendations [2, 19], many promising approaches have been merged into one intervention, encompassing cognitive training, focused physical exercise, socio-emotional development, and eHealth. This constitutes a daring endeavor in the quest for broad transfer, i.e. strengthened EFs leading to healthier dietary habits, more physical activity, stronger cognitive and academic performance, and improved socio-emotional well-being. Our program can be easily integrated into the school curriculum by adapting existing classes; it is not necessary to add extra time slots or replace entire classes. For this attempt at behavior change, appropriate guidance was found by following the steps outlined in the Intervention Mapping protocol [10]. By following the six IM steps, we were able to maximize the application of knowledge available in the realm of EFs and health promotion. Pilot-testing...
of all training and testing materials yielded almost exclusively positive feedback, although the number of participants was limited (5 teachers, 110 children). The result was a theoretically sound program ready to be delivered by teachers in elementary schools. Furthermore, after the effectiveness of TyM has been established, the plan is to implement it at the schools of the mother project “The Healthy Primary School of the Future” [72]. Much will depended on the implementation of, and adherence to, the program – both of which will be measured throughout (via the schedule provided in the manual, and the constant feedback loop), and after the intervention (via the evaluation form and interviews). Close contact between program developers and implementers (teachers) affects scientific purity of the research design as it creates an additional difference between experimental- and control schools, however, considering the novelty and scale of our intervention, we feel it is necessary to optimize feasibility and implementation in an attempt to truly test if EFs are trainable through TyM given solid implementation. Moreover, much can be learned from this feedback and collaboration to further improve and fine-tune future versions of TyM or similar programs. Ideally, future training programs will support implementers through online platforms. The ultimate goal was to make children happier and healthier, while they were basically having fun playing games and doing all sorts of activities. At this age (9-11), consistent training – or, as Diamond eloquently put it, ‘Disciplining the mind in the art of staying focused’ [9] – is best sugar-coated. Encouragingly, pilot-testing suggested that children were indeed enjoying themselves while undertaking our activities. In our larger RCT, we hope that such enjoyment drove motivation, adherence, and ultimately effective EF training.

Declarations

List of Abbreviations

CBS: Cambridge Brain Sciences

EFs: Executive Functions/Functioning

IM: Intervention Mapping

SEL: Socio-Emotional Learning
Ethics and consent to participate

Consent was obtained from the schools. Both parents and children were informed about the intervention and measurements, and both parents (written) and children (verbal) asked to provide consent. Parents and students can withdraw from participation at any time. This intervention, along with the study methods and consent procedure, were approved by the Ethical Review Committee of the Faculty of Psychology and Neuroscience, Maastricht University, the Netherlands (dd. 13-08-2015, ERCPN-06-06-2015).

Consent for publication

Not applicable.

Availability of data and materials

Data is not yet available. Materials can freely be requested from j.boveets@maastrichtuniversity.nl

Competing interests

Conflict of interest: HdV is the scientific director of Vision2Health, a collaborating company between Maastricht University and OverNite Software Europe with the aim of offering proven effective methods in the field of health education. JB, LJ, SM, and GK declare that they have no conflict of interest.

Funding

This project is funded by the Limburg provincial authorities (project number: 200130003), and Maastricht University.

Authors contributions
JB, LJ, GK, SM, & HdV conceived of the study and developed the materials. JB, LJ, & GK drafted the manuscript. All authors provided feedback on the manuscript, and read and approved the final text.

**Acknowledgments**

The development and preparation of the current study would not have been possible without the contributions of Raesita Hudales (elaborate creation & pilot-testing eHealth), Megan Talboom (creation & pilot-testing cognitive group games), and Svenja Wicht (pilot-study Kung fu and EF battery).

**Multimedia Appendix 1:** The TyM manual and several cognitive group games.

**Multimedia Appendix 2:** Example of the eHealth certificate with three personally chosen goals. Graphic design by Jessica Mayer Koren.

**References**


22. Hu FB. Resolved: there is sufficient scientific evidence that decreasing sugar sweetened beverage consumption will reduce the prevalence of obesity and obesity-related diseases. Obesity Reviews. 2013;14(8):606-19.


