Measures of Working Memory, Motivation, and Time Perception

Submitted by Daniel Labbé to the University of Skövde as a final year project towards the degree of M.Sc. at the School of Humanities and Informatics. The project has been supervised by Torkel Klingberg, Sakari Kallio, and Sissela Bergman Nutley.

September 2, 2012

I hereby certify that all material in this final year project which is not my own work has been identified and that no work is included for which a degree has already been conferred on me.

Signature: ________________________________
Measures of Working Memory, Motivation, and Time Perception

Daniel Labbé

Division of Cognitive Neuroscience

School of Humanities and Informatics

Skövde University
# Table of Contents

Introduction .......................................................................................................................... 8

Working Memory .................................................................................................................. 11

  Working memory training ................................................................................................. 12

  Working memory and motivation ....................................................................................... 13

Motivation .............................................................................................................................. 16

  Adaptive cognitions in motivation .................................................................................. 18

  State motivation .............................................................................................................. 19

Time Perception .................................................................................................................... 20

  Time perception in children ............................................................................................ 21

  Time perception in complex tasks, and motivation .......................................................... 22

The Timely Coordination of Working Memory in Motivated Cognitive Systems .......... 23

  Sequential vs. coordinative working memory capacity ..................................................... 24

  Primary vs. secondary memory ......................................................................................... 27

  Crystallized vs. fluid intelligence ..................................................................................... 28

  Executive depletion vs. motivation depletion ................................................................. 28

Predictions ........................................................................................................................... 30

Method .................................................................................................................................. 34

  Participants ...................................................................................................................... 34

  Procedure ....................................................................................................................... 34

  Motivation questionnaires .............................................................................................. 35
Working memory games .............................................................. 35
Time reproduction task ............................................................ 37
Measures .................................................................................. 38
Games ....................................................................................... 38
Working memory ................................................................. 38
Time perception ..................................................................... 39
Motivation ............................................................................... 40
Data Analysis .......................................................................... 42
Distribution checks and outlier detection .................................. 42
Results .................................................................................... 44
Descriptives ............................................................................ 44
Working Memory Performance ................................................ 47
Toward a Time Perception–WM Model ....................................... 49
Motivation Outcomes .............................................................. 50
Discussion ............................................................................... 53
The Time Flying Construct might not Capture State Motivation ........ 53
Multiple Goal Reconfigurations Offset Time Perception Accuracy ........ 58
Further Limitations ................................................................. 59
Further Implications ............................................................... 62
Implications for applied working memory training ................. 63
Motivation, perceiving value, and two types of feedback ......... 64
Time perception accuracy relies on coordinative capacity. .................................66

Acknowledgements .............................................................................................................. 67

References ............................................................................................................................ 68

Appendix A: Missing data .................................................................................................. 83

Appendix B: Time reproduction task code ........................................................................... 84

Appendix C: Information letter ............................................................................................ 91

Appendix D: Informed consent ............................................................................................ 92

Appendix E: Motivation questionnaire .................................................................................. 93

Appendix F: Sensitivity analysis ........................................................................................ 109
Abstract

Recent studies have indicated a further need to investigate the role of motivation in working memory (WM) training and that time perception affects motivation. We addressed whether subjectively perceived time on task in reference to objective time on task could serve as an implicit measure of motivation, while controlling for individual differences in time perception. Here, the relationship between different measures of time perception, WM, and motivation was explored in healthy children. Fifty children in three natural groups (ages: 6-7, 8-9, 10-11) at a Swedish school participated. WM scores changed with age as expected. However, the absence of correlations between WM performance and intrinsic motivation were inconsistent with previous findings, presumably due to the low statistical sensitivity. Nevertheless, time perception accuracy ($r=0.318$, $p=0.043$) and state motivation ($r=0.434$, $p=0.005$) correlated with performance on task interference, but not WM. With some reservations due to low sensitivity, time perception accuracy appears to be linked to coordinative capacity required for shifting attention, but to a lesser degree sequential working memory capacity.

Keywords: working memory, time reproduction, motivation, coordinative capacity
Measures of Working Memory, Motivation, and Time Perception

Several studies have investigated the relationship between working memory and motivation (e.g., Autin & Croizet, 2012; Jaeggi, Buschkuehl, Jonides, & Shah, 2011), and working memory and time perception (for a review see Block, Hancock, & Zakay, 2010). However, the literature on motivation and time perception is sparse (Conti, 2001; Sackett, Meyvis, Nelson, Converse, & Sackett, 2009; Vohs & Schmeichel, 2003). One study has jointly studied time perception, working memory, and motivation in attention deficit hyperactivity disorder (ADHD), although with a limited set of motivation measures (McInernery, & Kerns, 2003). To our knowledge, however, these three components have not been studied simultaneously in a healthy sample. There is a clinical rationale for studying the mechanisms of working memory, motivation, and time perception. Two common factors relate these three processes to each other: 1) the coordination of attention over time to achieve certain goals, and 2) deficiencies in all three processes are manifested in attention deficit hyperactivity disorder (ADHD) (Bush, 2010; Hurks & Hendriksen, 2011; McInerney & Kerns, 2003; West et al., 2000). Working memory is the process of temporary storing and moment by moment updating of information (Baddeley, 2003, 2007; Goldman-Rakic, 1995). As such, working memory is a goal-directed process (Miller, Galanter, & Pribram, 1960), which can be trained (Klingberg, 2010; Klingberg, Forssberg, & Westerberg, 2002; Olesen, Westerberg, & Klingberg, 2004). Motivation, from the Latin movere – to move (Eccles & Wigfield, 2002), is the psychological ability that enables a cognitive system to turn inertia into goal-directed behaviour or cognition, in part by directing attention to a task, to maintain a goal-directed state, and to “regulate” that state by (re)appraising and (re)structuring goals (i.e. prioritizing) (see Simon, 1967). As such, motivation is limited by time constraints due to the real-time demands of goals (Simon, 1967), in the current case: those of real-time cognitive tasks in working memory training. Time perception is the cognitive ability to
perceive, estimate, and reproduce durations of time. As a cognitive process its accuracy is affected by the current allocation of attention and a certain aspect of working memory capacity (Dutke, 2005). Individual differences in time perception are likely to reflect differences in processing speed (Mayr & Kliegl, 1993). For example, the retrospective estimation of how much time was spent on a working memory task is less accurate in individuals with lower working memory capacity of a certain kind (Mayr & Kliegl, 1993; Dutke, 2005). Furthermore, Hwang, Shur-Fen Gau, Hsu, and Wu (2010) investigated the relationship between working memory and time perception in a dual-task; however, because the authors did not investigate individual differences in motivation they were concerned about their conclusions. Similarly, Chein and Morrison (2010) raise similar concerns in their study on a different dual-task. The current study attempts to demonstrate whether such concerns can be addressed using various measures of motivation across multiple working memory tasks designed for training.

In a recent working memory training study using the n-back task (see Gevins & Cutillo, 1993) subjects were instructed to rate their motivation, in terms of enjoyment, difficulty, and improvement on Likert scales using changing smiley expressions as visual aids (Jaeggi et al. 2011). After extracting factors, the researchers found that the training and non-training tasks did not differ from each other in terms of motivation. Rather than investigating motivation between tasks, the current study investigated the relationship between cognitive performance and motivation.

When subjects approach a task, how much they value the task (Choi, Fiszdon, & Medalia, 2010) and their beliefs about their own competence may affect performance (Eccles & Wigfield, 2002). Perhaps changing subjects’ beliefs would improve performance. In a recent experiment, participants (n=111) were to perform the reading span task, a task that requires working memory. The participants were divided into three groups. Each group
received different instructions: participants in the first group were instructed that the task was
difficult but that this implied that the participants were learning; the second group was also
instructed that the task was difficult, however, that the experimenter was interested in what
strategy participants used; the final group served as a control group and performed the task
without any prior suggestions related to task difficulty. The authors found that working
memory performance was higher in the group that reframed learning as a normal part of
learning. They further suggested that this is due to that the apprehensive threat of the task
demand was reduced (Autin & Croizet, 2012). Approach and avoidance are central concepts
in motivation as they relate to the goals of an individual (see Wigfield, Eccles, Roeser, &
Schiefele, 2009). To further optimize working memory training, motivation appears to be a
relevant factor that needs further investigation, especially in complex tasks with high task
demands, and conflicting goals.

The current study consists in two parts. One part is use-inspired basic research, which
aims at an understanding of the interactions of time-perception, motivation, and working
memory in a situated context. The other part of the study concerns the feasibility of newly
developed working memory training games. The latter part, commissioned on behalf of
Cogmed Systems, Pearson Clinical Assessment Group, concerns mainly the question: Is
performance consistent across age groups 6-7, 8-9, and 10-11? In addition, natural
observations, which are common at the beta stage testing of software, were made. Among the
basic problems of the current study the main purpose was to evaluate various measures of
motivation with an emphasis on the concept of “time flies when having fun”, in the context of
cognitive training. The secondary purpose was to further elucidate the link between time
perception and working memory performance, while considering motivation.

The current study only addresses descriptions of behaviour and cognition—to what
extent deficits in motivation or working memory contribute to the neuropathophysiology of
ADHD remains to be investigated (Bush, 2010). Having addressed the clinical and practical relevance, we now turn to theory. The theoretical aspects of the current paper take a serial processing view of working memory, time perception, and motivation (Simon, 1967). Theoretical accounts of working memory, motivation, and time perception are considered next in more detail.

**Working Memory**

Working memory enables interaction with complex information during the execution of tasks. When working memory was first introduced by neuroscientists in 1960 – in the context of cognitive planning – it was accompanied by a discussion on motivation. However, the understanding of the brain was then largely limited to gross anatomy, and neuroscientists were baffled at what appeared to be a shared space for both memory and motivation (Miller, Galanter, & Pribram, 1960). In the beginning of the cognitive paradigm, working memory originally reflected the process of manipulating and updating computer memory. Back in 1960 this was achieved by manually punching holes, which represented sequential storage and recall instructions, onto punch cards. This view is sometimes still reflected in the construct of executive control: “virtually a homunculus, a little man in the head” (Baddeley, 2012, p.14). The arduous task of manually sequencing programs was superseded by the rapid advancement of computer memory devices. Among today’s computer users, the intuitive understanding of the working aspect of working memory has since been lost.

In 1974, the hard working hole-punching homunculus turned into the more abstract entity termed executive control, and the working memory model was divided into modality-dependent streams of processing: visual and auditory (Baddeley, 2003). One of the more salient features of the model was the distinction that it enabled between working and short-term memory. This is currently one of the most accepted view of working memory, although
alternatives exist, such as the view that working memory is merely the instantiation of long-term memory (e.g. Cowan, 2011; see Baddeley, 2012 for a review). For now, it is worth noting that working memory researchers’ current understanding of working memory originates from a serial and sequential processing view. Whereas “serial” implies that individual pieces of information are processed one by one (Simon, 1967), “sequential” implies that information is processed in a timely fashion. However, this is not always the case as there are both error checking and interrupt mechanisms in cognitive systems, for example, in order to handle distractions or conflicting goals (Simon, 1967). Thus, the serial output can be delayed. (A serial processing view of cognition is by far the most parsimonious, because parallel systems can be emulated using very fast, sub-second, serial processing models, see Simon, 1967. For theory-driven modelling purposes only one may assume that there is a single process that instantiates multiple processes, both serial and parallel.)

As programming language evolved, error checking mechanisms became easier to implement, as well as the ability to run multiple programs. The programmer that ran programs using punch cards was a sequencer, very different from the programmers today, which handle complex and at times real-time processes. The latter places greater demand on cognitive flexibility and one ability in particular: coordination. Coordination will be considered in more detail, but the reader will benefit from a presentation of working memory training, motivation, and time perception first.

**Working memory training.** General intelligence has been linked to working memory capacity (Conway, Kane, & Engle, 2003), and perhaps it is thus not surprising to find working memory to be one of the most actively studied topics in cognitive psychology (Osaka, Logie, & D’Esposito, 2007). The capacity of working memory, however, is limited (Miller, 1956; Cowan, 2011). Yet, the working memory capacity limit appears to be plastic and cognitive training may increase an individual’s capacity under the following conditions:
training should be performed close to one’s capacity using an adaptive psychophysical method of threshold approximation and training should last 25 days across five weeks with at least 20 minutes per session (Klingberg, Forssberg, & Westerberg, 2002). Such training leads to neuroplastic changes in structural connectivity, changes in the density of dopamine receptors in the brain (Klingberg, 2010), and increased activity in parietal and prefrontal cortices (Olesen et al., 2004). However, the methodology of some working memory studies has been criticized on the basis that a single task cannot alone capture the working memory construct and hence, there is a need to show convergence on multiple tasks (Shipstead, Redick, & Engle, 2010). Furthermore, interpretations may suffer due to the absence of control groups or the presence of either inactive or non-contact control groups (Shipstead et al., 2010). Some of these concerns have been addressed by Jaeggi, Buschkuehl., Jonides, and Shah (2011) who claim that there is sufficient evidence that working memory training works. Instead, the authors suggest that emphasis should be given on specific training conditions. A more recent critical review suggests that working memory training does not always result in transfer to other tasks – the scores do not consistently improve on tasks assumed to be dependent on working memory – and that more double-blind studies are needed (Shipstead, Redick, & Engle, 2012). The current study uses multiple measures of working memory (in response to Shipstead et al., 2010), but as a descriptive pilot study it neither provides a control group, nor a training phase. Having introduced working memory training we now turn to the role of motivation in working memory performance.

**Working memory and motivation.** A prerequisite for educational achievement is general intelligence (Deary, Strand, Smith, & Fernandes, 2007). General intelligence is highly associated with working memory performance (Conway, Kane, & Engle, 2003). However, intelligence is not sufficient for educational achievement. In educational research motivation has long been regarded as an important noncognitive factor, as motivation affects
performance in school (Martin, 2008; Zimmerman, Bandura, & Martinez-Pons, 1992). However, only recently have education policies begun to assimilate recommendations based on assessments of noncognitive factors (Lipnevich & Roberts, 2012). From the very first coinage of “working memory” it has been suggested that working memory is influenced by motivation (Miller, Galanter, & Pribram, 1960; Goldman-Rakic, 1995; Baddeley, 2003). More recently, motivation has gained further interest from the community that researches working memory training. In this context, working memory and motivation have been studied in typically developing children (Jaeggi et al., 2011), in children with attention deficit hyperactivity disorder (ADHD) (Miranda, Colomer, Fernández, & Presentacion, 2012; Prins, Dovis, Ponsioen, ten Brink, & van der Oord, 2011), and in adults with schizophrenia (Choi, Fizsdon, & Medalia, 2010).

However, the measures of motivation in the training context have been restricted to explicit measures. Only self-ratings, such as in the questionnaire on current motivation (QCM) (Vollmeyer & Rheinberg, 2006), have been used to assess time perception as a motivation measure. In the time perception literature it is common to compare objective with subjective time measures, and thus achieve a combined measure of accuracy (e.g. Gautier & Droit-Volet, 2002). However, this is not the case in the motivation literature. Currently, implicit measures of motivation have included purely subjective estimates of whether time flew faster (Vollmeyer & Rheinberg, 2006) and purely objective measures of time spent on task as an indicator of motivation persistence (Habgood & Ainsworth, 2011). To our knowledge, this is the first study to investigate state motivation through a combined measure of objective and subjective measures of time perception, with the purpose of cross-validating the QCM questionnaire item with a more implicit measure. Implicit in this context is not to be confused with the use in literature on implicit motives (e.g. Schultheiss, 2008). Rather, the word implicit suggests an indirect measure of motivation.
There are two advantages of a combined measure over purely subjective and objective measures. In contrast to purely objective time on task measures, there is no need to wait for motivation failure. Stimulus presentations can be administered with a fixed duration. In contrast to purely subjective time flying measures, the duration judgement is normalised with reference to the objective time on task. This enables a comparison between tasks of different lengths and between individuals with different objective times on task.

We assume that implicit measures of motivation might minimize evaluation apprehension (Sansone & Harackiewicz, 1996), or otherwise performance anxiety in the presence of an experimenter. There is evidence that performance is influenced by evaluation apprehension, but not social cues in organizational settings (n=104, ages 20-38) (White, Mitchell, & Bell, 1977). There is further limited evidence to suggest that expecting a (peer) evaluation while attaining easy goals leads to higher intrinsic motivation compared to not expecting an evaluation (n=20, males, mean age=20), as does attaining difficult goals while not expecting an evaluation (Shalley & Oldham, 1985). The latter result is likely a consequence of task complexity-competence match. The current study sought to minimize apprehension of evaluation by hiding performance measurements from participants through withholding feedback on overall performance for each game, although changes of game level were displayed simultaneously with the adaptive tasks. Furthermore, participants were tested one by one in a separate room and were thus unable to be influenced by the presence of their peers.

The current study is motivated by the need to validate an implicit measure of state motivation: whether participants felt that time flew faster after task completion. One might speculate that implicit measures of motivation affect performance less between trials, then explicit ones, as implicit measures do not continuously require reflection of whether one is motivated or not. From a system motivation perspective, this causes unnecessary
motivational interrupts in the cognitive processing chain. In the current paradigm, however, motivation specific interrupts are substituted with cognitive interrupts: duration judgements of time spent in minutes compared to objective time spent on task. However, the switching of tasks that is required still represents a change in goal hierarchy, and thus current system motivation (see Simon, 1967).

Working memory tasks in themselves can be designed as more motivational with consequences for attention (e.g. Choi, Fiszdon, & Medalia, 2010), and the properties of games that enable optimal state motivation, or “flow”, can be investigated using functional magnetic resonance imaging (fMRI) (Klasen, Weber, Kircher, Mathiak, & Mathiak, 2011). Motivational instructions that boost self-estimations of competence affect performance on working memory dependent tasks in healthy (Autin & Croizet, 2012) and schizophrenic samples (Choi, Fiszdon, & Medalia, 2010).

Motivation

The computer metaphor of working memory readily explained memory processes, but even the neuroscientists who introduced “working memory” had difficulties reconciling this view with a motivational system (Miller, Galanter, & Pribram, 1960). More recently, working memory researchers’ interest in motivation has resurged in the context of working memory training. One of the studies that investigated motivation in working memory training concerned the motivational properties of the tasks (Jaeggi et al., 2011), but did not explicitly seek out the relationship between individual motivation processes and working memory performance. The choice between investigating task-specific and subject-specific motivation reflect only some of the diversity of motivation studies. Four different constructs of motivation can be construed, which correspond to four different units of observation: cognitive systems have a baseline motivational state or goal configuration, tasks can be
intrinsically motivational and pursued as goals in themselves, goals provide incentives (motives) for action, and specific situations or timely conditions may provide different degrees of motivation. Hence, we distinguish between individual or (1) system motivation (Simon, 1967), task-inherent or (2) intrinsic motivation (Deci & Ryan, 2000), incentive-based or (3) extrinsic motivation (Deci & Ryan, 2000) and situation- or time-specific (4) state motivation (Vollmeyer & Rheinberg, 2006).

The current empirical investigation restricts itself to intrinsic and state motivation, while the theoretical discussion includes a view based on system motivation. System motivation is a task-dedicated type of executive control of attention within real-time constraints (Simon, 1967). The advantage of this narrow model of motivation is that it can be seamlessly combined with a cognitive information processing view, in which cognitive processes are interrupted due to motivational changes. Such changes can be described algorithmically in a goal-hierarchy structure (Simon, 1967). However, alternate models of motivation exist in behavioural neuroscience, including the limited view of motivation as incentive-based motivation, which corresponds to extrinsic motivation in educational research, or as a biological homeostatic drive (Berridge & Robinson, 1998). Similar energy based models have recently been suggested from a cognitive perspective (Kruglanski, Bélanger, Chen, Köpetz, Pierro, & Mannetti, 2011). Although the behavioural models are successfully applicable to the expression of primitive needs and reflexes, the lack of an information processing framework disables the analysis of interactions between cognition and motivation. Hence, there is a need for contemporary cognitive neuroscientists to adopt a system(s) motivation view. The valuable lesson from behavioural neuroscience, however, is the anchoring of motivation in evolutionary driven biological processes. For example, animal models of approach and avoidance motivation have successfully been reproduced in humans (Gonen, Admon, Podlipsky, & Hendler, 2012). Meanwhile, the cognitive energy view has not
sufficiently matured yet, as it does not consider multiple goals (Kruglanski et al., 2011), an aspect that is presumably crucial to understanding conflicting goals during the coordination of resources in complex tasks.

In contrast to system motivation as introduced by early cognitivists, educational psychologists focused early on the contrast between intrinsic and extrinsic motivation (Deci & Ryan, 2000). The motivation associated with a task per se is defined as intrinsic motivation, while motivation driven by task-independent external incentives – often dependent on task-completion, for example, rewards and punishments – is defined as extrinsic motivation (Deci & Ryan, 2000). In the current paradigm, feedback on performance was kept constant and to a minimum. Thus, we control for extrinsic motivation. Instead, we focused on the tasks in themselves. For the final type of motivation, state motivation refers to the neural and subjective state of subjects, which stresses the situatedness and the time-bound nature of motivation. State motivation is often the combined result of baseline motivation, intrinsic, and extrinsic motivation. We distinguish between state motivation: affects, experiences, and implicit motives – and a cognitive motivational state: a list of priorities (system goals that can be formally listed in a hierarchical fashion with different degrees of emotional or rational appraisals, or even stochastical decision criteria).

Adaptive cognitions in motivation. Motivation research is a fragmented field of inquiry, in which studies rarely go beyond assessing only a few motivation aspects (Martin, 2008). To remedy this state of affairs, Martin (2008) organized motivation aspects into two diametrical dimensions, resulting in four subfields of inquiry or intervention: adaptive cognitions, adaptive behaviours, maladaptive cognitions, and maladaptive behaviours. The current study is limited to the adaptive cognitions domain, which includes: self-efficacy, mastery orientation, and valuing. In addition, optimal state motivation probably belongs in this domain. These aspects of motivation are described next.
Self-efficacy is a subject’s confidence in her competence to successfully perform a task (Eccles & Wigfield, 2002). Self-efficacy for working memory tasks has previously been studied in schizophrenia (in adults), where it appears to be related to task value (Choi, Fiszdon, & Medalia, 2010). Mastery-orientation and competitiveness/performance-orientation are two types of goal-orientation. Mastery-orientation emphasises the drive to master a challenge, while performance-orientation emphasises the drive to outperform others (Fairchild, Horst, Finney, & Barron, 2005). Goal-orientation aspects are closely related to valuing a task. Furthermore, the ranking of the games according to preference after completing the main task is likely to reflect interest and feasibility between ages. To what extent an individual processes information depends not only on cognitive ability, but also on how much they value processing a particular piece of information, whether they rate themselves as competent to successfully process it, and whether they experience that the processing required matches their competence (Choi, Fiszdon, & Medalia, 2010; Eccles & Wigfield, 2002).

State motivation. Motivation constructs such as the ones just presented, usually require some kind of self-report from participants. To avoid continuous evaluation during game play as much as possible the current study asked most motivation questions using pre- and post-questionnaires. To ensure a measure closer in time to task performance, participants were asked to estimate the duration of game play retrospectively after each game. Optimal state motivation, also known as flow, is characterized by a sense of time flying (Vollmeyer & Rheinberg, 2006). To establish a more reliable measure than merely asking whether time was experienced more rapidly than otherwise, as in the Questionnaire on Current Motivation (QCM) (Vollmeyer & Rheinberg, 2006), for each game the reported subjective time-on-task estimation was compared with the objective time on task.
In addition, a pure measure of time perception (i.e. in the absence of cognitive load) was used. The initial idea was to account for individual differences between participants in internal clock speed. Inaccurate time perception is associated with ADHD in children (Hurks & Hendriksen, 2011; Smith, Taylor, Rogers, Newman, & Rubia, 2002; West et al., 2000) and problems with delay of gratification (Corvi, Juergensen, Weaver, & Demaree, 2012). More generally, low working memory capacity is associated with more accurate time perception in conjunction with cognitive tasks, because low performers direct attention away from the task (Woerhle & Magliano, 2012).

**Time Perception**

Dopamine is involved in both motivation (e.g. Volkow et al., 2009, 2011) and working memory (e.g. Klingberg, 2010), but also in time-perception (e.g. Wiener, Lohoff, & Coslett, 2011). Dopamine is a substance that affects processing more generally across multiple neurons: a neuromodulator (Seamans & Young, 2004). Its role in cognition, in amplifying or attenuating signals, is affected by 1) optimal, suboptimal, and excessive neurochemical concentrations; 2) the neural site of activation; 3) the speed of firing neurons, and the complex interactions of several additional factors (Seamans & Yang, 2004). For example, under certain conditions dopamine might enhance the signal of neurons that fire at higher frequencies while subduing the effect of neurons that fire at lower frequencies (Seamans & Yang, 2004). There appears to be two different types of timing of relevance to neural processing: time perception in the sub-second interval range (i.e. below one second) is associated with nigrostriatal dopamine, while supra-second intervals are associated with mesocortical dopamine, suggesting a double dissociation based on genotyyping and behavioural performance (Wiener et al., 2011). (Nigrostriatal and mesocortical dopamine are distinguishable based on the site of their activations. For example, whereas nigrostriatal dopamine is present in structures associated with the initiation and coordination of
movements, mesocortical dopamine is associated with prefrontal neuromodulation and working memory. See Wiener et al., 2011.)

In addition, the genotype associated with supra-second time perception and prefrontal dopamine (Wiener et al., 2011) has been associated with training-induced plasticity (Söderqvist et al., 2012) and the development of visuospatial working memory (Dumontheil et al., 2011). In the current study, only supra-second intervals are considered as is only visuospatial aspects of working memory. In summary, time perception tasks vary in duration. Tasks completed under and above the 1 second mark appears to engage different neural systems (Wiener et al., 2011).

**Time perception in children.** Because the configurations of neural systems vary with age, individual differences in time perception also vary with age. Children’s performance on time reproduction tasks are accurate at 8 years of age, but are likely to be erratic at 6 years of age (Espinosa-Fernández, de la Torre Vacas, del Rosario García-viedma, García-tuiérrez, & Jesús Torres Colmenero, 2004). This is plausibly due to a developmental shift between these ages and the acquisition of time related concepts (Pouthas, 1985 as cited in Espinosa-Fernández et al., 2004). Furthermore, an understanding of conventional units of duration, such as minutes, varies in younger children (Pouthas, 1985 as cited in Espinosa-Fernández et al., 2004). Yet, younger children have an accurate sense of time as demonstrated by studies on temporal bisection, and temporal production even in children of two and a half years of age (see references in Espinosa-Fernández et al., 2004). Three criteria are required for optimal measurements of time in young children (see references in Espinosa-Fernández et al., 2004): 1) an explicit instruction of the need to wait, 2) an interesting task, and 3) a brief number of trials. The current study presents explicit instructions on screen, a brief training task, and a challenge or “game”, where the participants are instructed – both on screen and verbally – to respond as accurate as possible, and only three trials are presented. The practice
trials are very brief. The whole time reproduction task takes less than two minutes to perform. Thus, we consider these criteria to be fulfilled. However, there was no prior demonstration of the task by the experimenter (see Espinosa-Fernández et al., 2004).

One study demonstrated no differences between age groups 5 and 8 year olds while performing a dual-task consisting of one temporal and one non-temporal component (Gautier & Droit-Volet, 2002). This is a null-finding and should be interpreted with caution. However, the study also showed that duration judgements in 5 year olds are more variable than in 8 year olds. In addition, there is some evidence that 8-10 year olds differ from 11-30 year olds at duration estimates at 5 minutes, but their performances do not differ from 31-70 year olds in a sample of 140 participants (Espinosa-Fernández, Miró, Cano, & Buela-Casal, 2003). However, there are no differences for the younger group at 10 seconds and 1 minute interval estimations, intervals that are closer to the ones used in the time reproduction task of the current study.

Boys (ages 8-12) with ADHD, in the absence of a cue, tend to make more underestimations of time compared to cued conditions (Sonuga-Barke et al., 1998). Participants in the study made more overestimations or responded too late. This finding emphasises how attentional cues contribute to time perception. Next, we turn to how temporal cues shape time perception and the implications of time perception in complex tasks.

**Time perception in complex tasks, and motivation.** Time perception is associated with the number of discrete events during a task: in an indigenous experiment time perception was shown to depend on visual processing of segmented dynamic paths, suggesting that time appears to fly faster when subjects are exposed to multiple events (i.e. more segments) compared to fewer (Liverence & Scholl, 2012). However, subjects tend to attribute
motivational enjoyment – having fun – to the belief that they experienced time flying rather than their actual experience of time (Sackett, Meyvis, Nelson, Converse, & Sackett, 2010). Taken together, these results suggest that having fun is due to engagement in complex tasks, which require greater coordination and thus consume more cognitive resources of attending to time, thereby diminishing the time experienced (see Meck & Benson, 2002). Perhaps these complex tasks are more fun, which is presumably due to that the goals of complex tasks, once attained, are more enjoyable than the outcomes of simple tasks.

Simple timing tasks are also of importance in investigation time perception. Adults with ADHD attempted to drum in synchrony with a slow metronome, but performed at a faster tempo than that of controls. However, these deviations were only detected at a slow tempo within 2 second intervals (i.e. super-second intervals) (Gilden & Marusich, 2009).

**The Timely Coordination of Working Memory in Motivated Cognitive Systems**

Some authors assume that all goal configurations are processed by working memory (e.g. Jaeggi, Studer-Luethi et al., 2010; Logan, 2004). From this perspective one would expect that the correlates of motivation and those of working memory would be difficult to tell apart. Few studies have currently addressed the neuroscience of motivation in more than behavioural terms (Gonen et al., 2012; Bengtsson, Lau, & Passingham, 2009). However, primary evidence from a recent rigorous connectivity analysis suggest that conflicts between motivational goals correlate with activity in the ventromedial prefrontal cortex, which feed forward signals to the hippocampus (Gonen et al., 2012). The hippocampus is associated with long-term memory and episodic memory, but working memory does probably not dependent on this structure (Jeneson & Squire, 2012). The ventromedial prefrontal cortex is associated with emotion based decision-making (Bechara, Damasio, Damasio, & Lee, 1999) and “goal-directed action selection” (O’Doherty, 2011, Title). Further evidence suggests that activity in
the ventromedial prefrontal cortex correlate with the protection of recently configured task rules from distraction (Bengtsson, Haynes, Sakai, Buckley, & Passingham, 2009). The take home message here is that the current paper assumes that motivation goals (emotion-based selections; e.g. task sets/instructions/rule settings/goal configurations) and cognitive goals in working memory (attention-based selections; e.g. priority of conscious over preconscious information) are processed separately.

Research does not only support a distinction between processing motivation goals and cognitive goals. Several researchers have suggested that working memory is not a unitary phenomenon (Baddeley, 2012; Dutke, 2005; Unsworth & Engle, 2007). This is not surprising as the current construct appears difficult to measure reliably, especially when tasks place higher demands on time-constrained coordination. Working memory training appears to be efficient under some conditions, but results are inconsistent even when using a single measure of working memory. For example, the reliability of the dual n-back task is sometimes higher than that of the single n-back task, but sometimes lower (cf. Jaeggi, Studer-Luethi, Buschkuehl, Su, Jonides, & Perrig, 2010; with Jaeggi, Buschkuehl, Perrig, & Meier, 2010). Possibly, individual differences in different subcomponents of working memory might explain the varying results between various working memory measures, suggesting that working memory is not a unitary process (Jaeggi, Buschkuehl, et al., 2010). Next, we will consider different ways authors have suggested that working memory can be compartmentalised, in part by evidence from the time processing domain.

**Sequential vs. coordinative working memory capacity.** In contrast to working memory, which is described as consisting in multiple components (Baddeley, 2012), working memory capacity is often regarded to be a unitary phenomenon. The analogy based on the early computer programmer assumed the intuitive view that capacity was limited on a sequential basis. The handling of interrupts, of multiple competing processing goals, has not
yet been considered in Baddeley’s (2012) model. A few studies in the time perception domain have suggested that working memory capacity is bipartite (Dutke, 2005). On this view, there is sequential working memory capacity and coordinative working memory capacity. Whereas sequential working memory capacity refers to the traditional capacity concept in which subjects process stimulus by stimulus by singling out a property, such as the position in a visual matrix, coordinative working memory refers to subjects responding to multiple properties of a stimulus. Two types of tasks are used to investigate coordinative working memory capacity: simultaneous and consecutive tasks. Simultaneous tasks are often referred to as dual-tasks or complex tasks, although consecutive tasks include dual elements too. In keeping with previous nomenclature, in a dual-task participants are required to respond to two varying stimulus-properties close in time within a trial, often simultaneously (e.g. color and number), while consecutive tasks present a different task for each trial. Consecutive tasks, in turn, belong to either one of two categories (cf. Huizenga, van der Molen, Bexkens, Bos, & van den Wildenberg, 2012): task-switching or task-interfering. Whereas task-switching is self-explanatory, task-interfering experiments include an early administered task designed to interfere with a task that is administered subsequently, thereby depleting resources, for example, pertaining to cognition or motivation. The task-interfering paradigm should neither be confused with priming experiments nor tasks where participants are required to ignore distractors.

From a serial processing perceptive, coordinative capacity can be reduced to sequential capacity if one considers the possibility that coordination is merely a subroutine that is part of a sequence. The difference between sequential and coordinative working memory would then consist in the stricter time constraint that is characteristic of coordinative demand. The time constraint is a characteristic of the systems motivation framework (Simon, 1967): motivation for cognition is time constrained under high cognitive load. If this holds
true, then sequential training at a certain difficulty would correspond to coordinative training at the lowest difficulty – and the processes would be characterized by similar processing speeds. In other words, if one would be able to constrain sequential demands to time constraints similar to those of coordinative demands, one would activate the same working memory process. No additional cognitive faculty would need to be postulated (see Simon, 1967 for a more general argument against dual processing views on memory). However, the possibility still exists for these processes to be distinguishable on the neural level of explanation. Indeed, a double dissociation between dopamine related genes was found between processing of sub- and supersecond time intervals (Wiener et al., 2011), suggesting that working memory processing can occur under two types of time constraints.

Continuing on the assumption of a serial processing view, the sub-processes of a task are processed one by one, sequentially. Task complexity affects performance and may increase in two dimensions: sequentially and coordinatively. In aged populations, slower processing is associated with both coordinative and sequential processing. However, the change in processing speed can to a greater extent explained by coordinative complexity, compared to sequential complexity (Mayr & Kliegl, 1993). The relevance of processing speed for the current study is mainly that failure of retaining working memory contents could be due to slow processing (Mayr & Kliegl, 1993).

In a series of four experiments Dutke (2005) ascribed these dimensions of task complexity to working memory capacity by demonstrating that there are two different types of cognitive loads than can be placed upon working memory capacity: sequential demands and coordinative demands. When the cognitive demands are taxing the system time-frame by time-frame – there is sequential demand. Sequential demand corresponds to the traditional working memory span that is typically manipulated in adaptive working memory training. For example, the number of blinking lamps (span) displayed in a sequence in the visual data
link (VDL) task, where participants are required to recall the order of presentation (sequence). In contrast, when the cognitive demands are of a coordinative nature, there is a switch of attention between multiple properties of a stimulus that require working memory processing, such as mental rotation (Mayr & Kliegl, 1993) or multiple response options while counting occurrences of multiple numerical targets (Dutke, 2005). Dutke (2005) compared two conditions within subjects while they counted the occurrences of numbers in a list, until a certain target was reached (e.g. three occurrences): in the first condition, participants made a binary [Yes, No] decision; in the second condition, participants made a quaternary [Yes: 16, Yes: 38, Yes: 67, No] decision. After each condition participants were to reproduce the time spent on the task. In the condition of increased coordinative demand (multiple choice), participants reproduced the time less accurately. These findings suggest that the central executive becomes taxed during dual-task administration of a temporal and a non-temporal task, and that time perception is dependent on temporal cues (see also Liverence & Scholl, 2012).

**Primary vs. secondary memory.** Dutke’s theory offers the idea that working memory capacity is two-dimensional (2005), suggesting different neural correlates but a single neural substrate. In contrast, a second theory holds that there are actually two different ontologically separable working memory entities, suggesting two neural substrates. Recently, Gibson and colleagues (2011) suggested that working memory training can be further improved, depending on what aspect of working memory is targeted. According to Unsworth and Engle (2007) primary memory (PM) is the online maintenance of working memory as measured using span tasks, while secondary memory (SM) accounts for the retrieval process after interruption of online maintenance. In this regard, secondary memory resembles a repair function of partly lost information. There appears to be a need to further investigate interrupting working memory tasks in which the processing of seven objects or more interfere
Gibson and colleagues found that only primary (PM), but not secondary memory (SM) in participants aged 11-16 year with ADHD (n=40) improved after working memory training. However, in the study only 17 participants received visual working memory training. The implications for the current study are thus limited.

**Crystallized vs. fluid intelligence.** According to Baddeley (2012), the distinction between primary and secondary memory reflects the distinction between crystallized and fluid intelligence (Cattell, 1963) as reintroduced in Baddeley’s multi-component model of working memory (Baddeley, 2007). Crystallized intelligence is the specific outcome of learning due to previous application of general skills and is associated with memory recall, while fluid intelligence is a biologically driven intelligence factor that is adaptive to new situations (Horn & Cattell, 1966; Catell, 1963). A good indicator of crystallized intelligence is the requirement of pretraining for a task (Horn & Cattell, 1966). Fluid intelligence is associated with development and changes with age. It has furthermore been associated with maintenance of working memory span, the perception of relations, and processing that is task-bound or “online” (Horn & Cattell, 1966). Traditionally, it was regarded as a stable factor, but more recently it has preliminary been shown to change due to cognitive training in very young children, age 4 (Bergman Nutley et al., 2009). One limitation with the distinction between these intelligences is the vagueness of these terms as they each appear to refer to distinct functional sets, including functions such as maintenance and recall. The distinction between crystallized and fluid intelligence alone does not account for their relation when both are engaged during the same task, in contrast to the articulate distinction between maintenance and recall, which both require memory contents.

**Executive depletion vs. motivation depletion.** A more recent account emphasises that the allocation of cognitive resources during high self-regulation demands drives time
perception, which in turn drives motivation. A study which suggested that self-regulation behaviour results in depletion of regulatory resources, predicted that decrements in performance can be attributed to self-regulation failure because subjects experience an elongation of time (Vohs & Schmeichel, 2003). The authors argued that self-regulation in cognitive tasks often require that subjects pay attention to time, and thus subjects' time perception is altered, resulting in a subjective feeling of "an extended-now state" (Vohs & Schmeichel, 2003, p.219), which in turn increases the likelihood of resource depletion. When the execution of tasks appears to move in slow motion, the reaching of task goals appear more distant in time. In such a state, subjects are likely more concerned with actions with immediate consequences, rather than long-term goals (Vohs & Schmeichel, 2003). However, in a more recent study on inhibition of sequential cognitive control, the authors concluded that motivation is independent form the depletion of resources (Huizenga et al., 2012). Taken together, these studies either suggest that the motivation measures in the latter study do not represent self-regulation, or that both motivation and cognitive resources can be depleted over time. The latter statement implies that not only depletion resilience can be trained using working memory training, but that resistance to self-dysregulation can be boosted too. Indeed, resistance to depletion of self-regulation can be trained (Muraven, Baumeister, & Tice, 1999; Oaten & Cheng, 2006). It is worth noting, however, that performance decrements may not always reflect depletion of resources, but the adaptation of a low-effort strategy that enables sustained performance over time (Hockey & Earle, 2006).

Inefficient use of neural resources may not only occur after longer bouts of self-regulation. One momentary manifestation of decreased performance due to resource allocation occurs when subjects switch between two different tasks. Task-switching (for a review see Monsell, 2003) introduces delayed response times due to task-set reconfiguration. This delay is referred to as a task-switching cost, on the basis that cognitive resources are
limited. In a series of alternating trials, which require task-switching, the results from two different tasks can be explored in a “task-span” procedure (Logan, 2004). Task-span refers to the number of correct responses during switching between multiple tasks. The first study on task-span suggested that working memory was not occupied by task-sets (Logan, 2004). The author raises the possibility of multiple executive controllers. On this view, one controller would perhaps resemble a task identifier (find appropriate task set), a second would retrieve instructions (locate and switch task set), while a third process would instantiate the task (execute task set). Apart from multiple controllers, the author implied a memory system in addition to working memory. When switching task rules –i.e. goal set – while keeping stimuli constant, task rules are kept in some sort of memory in order to stay protected from distraction, as demonstrated by sustained activation in ventral prefrontal and possibly frontal polar cortex (Bengtsson, Haynes, Sakai, Buckley, & Passingham, 2009).

Predictions

We hypothesised that children’s performance is likely to depend on both motivation and different types of processing demands. Compared to previous games, the recently developed games are characterized by increased processing demands. Furthermore, we predicted a link between working memory, motivation, and time perception, because failures of all three have been implied in ADHD (Hurks & Hendriksen, 2011; McInerney & Kerns, 2003; Smith et al., 2002; Volkow et al., 2009; Volkow et al., 2011).

Any performance measure is expected to correlate with intrinsic motivation, as it reflects the intrinsic value of a task. However, state motivation reflects a different quality, namely the subjective feeling of engagement or immersion (see Klasen, Weber, Kircher, Mathiak, & Mathiak, 2011). High accuracy in time perception would suggest a low degree of immersion – time does not fly when one is able to cope with distractions.
Assuming both math score and working memory capacity reflects performance (Vollmeyer & Rheinberg, 2006), we expect significant correlations between state motivation and the performance measures for working memory (WM), game, and the maths task. In extension to this prediction, state motivation is predicted to mediate the relationship between initial motivation and performance scores (WM, maths) (Vollmeyer & Rheinberg, 2006). See Figure 2.
To test the validity of the state motivation index, it is expected that the change in $D_{J_{Ratio}}$ explains more of the error variance in state motivation than a restricted model without it, featuring only $TOT_{Ratio}$:

**Unrestricted model:** State motivation = $\beta_0 + \beta_1 TOT_{Ratio} + \beta_2 D_{J_{Ratio}} + \epsilon$

**Restricted model:** State motivation = $\beta_0 + \beta_1 TOT_{Ratio} + \epsilon$

$H_0$: $\beta_2 = 0$

$H_1$: $\beta_2 \neq 0$

The next prediction proposes that there is a decrease in intrinsic motivation for each stepwise increase in age (6, 8, 10 years old), as have been shown from 3rd graders to 8th graders (Lepper, Iyengar, Henderlong Corpus, 2005; also see references in Henderlong Corpus, McClintic-Gilbert, & Hayenga, 2009). Model:

**Intrinsic motivation** = $\beta_0 + Age + \epsilon$
We further expect that working memory scores positively correlate with accuracy of time perception between individuals (Woehrle & Magliano, 2012). This relationship is presumably bidirectional (Woehrle & Magliano, 2012), and hence a simple regression model is not sufficient. Furthermore, we expect that working memory capacity partially accounts for math score:

$$\text{Math score} = \beta_0 + \beta_1 \text{Working memory capacity} + \epsilon$$

A possible link between working memory performance and mathematical performance may not easily be established because number acuity – the ability to numerically distinguish clustered items of different sizes – might act as an intervening nuisance variable. For example, dyscalculia has been associated with underdeveloped number acuity (Piazza et al., 2010).

The current non-experimental correlational study is limited to descriptions in the absence of causal inference. A chief limitation is that participants make up natural groups and are not randomly assigned. The causality implied by the arrowheads in Figure 2 is based on a previous paper and is not recapitulated in the current conclusion. Especially in the context of training it is possible that cognitive training increases performance in maths, but also that completing math exercises over time influences working memory. For these reasons, we refrain from the labels “independent” and “dependent” variables and instead refer to variables as predictors or criterion variables (Tabachnik & Fidell, 2007). Predictors include any right-hand expression in the models above, while criterion variables refer to the other variables subject to regression.
Method

Participants

Fourteen preschool children, 26 second graders, and 10 fourth graders (age range: 6-11, $\bar{x}=8.16$, $SD=1.656$) were recruited from a Swedish public school in central Stockholm ($N=50$, 26 females). After phone calls with the principal, a letter of invitation and an informed consent form) were distributed (Appendices C and D, text version only). Teachers forwarded the information in either the weekly newsletter of the class or per email to the parents. Six participants were excluded (valid $n=13$, 22, 9; total valid $n=44$). One participant withdrew during the beginning of the study. Five were excluded due to technical problems with the data recording or due to frequent interruptions during testing.

Participants were eligible if they belonged to 1) a matched age group and 2) one of three classrooms. Informed consent forms were gathered from parents. Participants received a non-refundable voucher, which could be exchanged for a movie ticket at the majority of Swedish movie theatres. Availability and principals’ interest determined choice of public school in central Stockholm. When the minimum sample size criterion of 10 in each group was fulfilled, another class and another school were excluded from participation due to time constraints.

Procedure

A brief presentation about the investigation was held in each class. In a separate room adjacent to the classroom, participants were tested one by one. To facilitate naturalistic observation, each group was studied in a familiar room, and hence three different rooms. The test administration lasted around 40 minutes per participant. Participants answered motivation related questions prior to a brief maths test and a working memory test: odd one out (OOO)
(Alloway, Gathercole, & Pickering, 2006). After these tests, participants played four different computer games designed for working memory training. The games were presented in a true random order. (The randomised order was generated using www.random.org.)

**Motivation questionnaires.** Questionnaires were rearranged for each participant to reflect the different orders of presentation. After each game, participants were asked two questions on state motivation. Having completed all games, participants were asked a series of motivation related questions about their gaming experience and whether they play other computer games. Throughout the procedure, the “experimenter” filled in a structured questionnaire based on verbal answers from participants (see Appendix E, with one of the randomizations of game order in place) and took notes of possible confounds through natural observation.

**Working memory games.** On a laptop connected to an external wireless mouse, the four games were presented: Visual Data Link (VDL) (Gibson et al., 2011), the spatial complex working memory task (CWM) (based on Chein & Morrison, 2010), n-back task (based on Jaeggi et al., 2011), and Space Mines Patrol (SMP) (Cogmed, in development; for the English version visit www.spaceminespatrol.com). All instructions were given in Swedish. Some of the games had instructions recorded, while some were introduced by the experimenter who read from a script. After the administration of the questionnaire, the time reproduction task (TRT) (c.f. McInerney & Kerns, 2003) was presented on a second laptop (see Figure 1). After a practice trial of 3 times 1 second, participants aimed to reproduce intervals of 10, 12, and 14 seconds – in that order – by pressing and holding down space bar. The twelve second interval has previously been used in a dual-task procedure in children at 5 and 8 years of age (Gautier & Droit-Volet, 2002). The choice of a time reproduction task over a production task is threefold: 1) the separate time task can be compared with retrospective accounts of the time spent on games, and 2) in a study on participants with ADHD using both
types of measures, underestimation on the time reproduction was associated with inattention, while overestimation on the time-production task was related to impulsiveness (Hurks & Hendriksen, 2011) – the current study assumes that attention, rather than impulsivity, is more relevant to several of the tasks – and 3) the task does not rely on the ability of children to understand conventional units of duration, such as seconds (Pouthas, 1985).

The CWM task includes a distracting mirror task, where participants decide whether two vertically opposing squared patterns are mirrored or not. To confirm that participants understood the difference between vertical mirroring, similarity (i.e. asymmetrical copy), and difference, participants were required to distinguish a series of cards prior to the game (see Figure 1). Thus, the presentation of the mirror task was locked to the random order of presentation of the CWM game. Parameters: 15 trials; difference between mirrored images = 7 squares; progression rule: recall only; no feedback on mirroring errors.
With the exception of the graphical user interface and rules, the \( n \)-back task was similar to previous presentations for children, with only 6 positions in a hexagonal pattern (Jaeggi et al., 2011). The \( n \)-back task was presented in a two-alternative forced choice (2AFC) response mode: on target, participants were instructed to press Space bar; on non-targets, to press Z.

Modified rules for the \( n \)-back: if \( \leq 3 \) errors, ascend one level; if \( \geq 4 \) errors per round in 2 subsequent rounds, descend one level. Parameters: trials = 15 + \( n \), targets/level = 5, rate = 3s, stopping rule = 6 rounds, stimulus length = 500ms, interstimulus interval = 2500 ms; random positions.

**Time reproduction task.** The Time reproduction task (TRT) was programmed in PXLab, a collection of JAVA classes for psychophysical experiments PXLab (Irtel, 2007). A light bulb lights up to the left (Figure 2). When the light goes off, the user is asked to reproduce the time it was alit by pressing and holding down space bar. Thus deviations could be measured for accuracy (i.e. the mean) and precision (i.e. standard deviation). (The TRT code is reproduced in Appendix B). Because the order of presentation has previously been
shown not to influence the TRT outcome in 6-13 year old children, $F(2, 55)=0.22, ns$ (results from McInerney & Kerns, 2003) there was no need to randomize the presentation of the stimuli, which were presented sequentially: 10, 12 and 14s.

**Measures**

**Games.** The games produced scores – correct answers. The n-back provided an exception as it was based on a composite measure accounting for hits and misses, as well as false alarms and correct omissions. For the CWM task, both the grid task score and the mirror scores during the interleaved distraction phase were computed.

**Working memory.** Working memory capacity was measured using the OOO task (Alloway et al., 2006). Alternate indicators of working memory capacity were retrieved from the game set. For all games, WM performance is represented by the maximum level of difficulty reached. The math task measures percent correct.
Time perception. Objective time on task (TOT) and retrospective subjective estimates of time on task were recorded immediately following each game. A time on task ratio is calculated for each game:

$$TOT_{Ratio} = \frac{TOT_{Subjective}}{TOT_{Objective}}$$

In addition, a deviation score was calculated:

$$TOT_{Deviation} = TOT_{Objective} - TOT_{Subjective}$$

Whereas the ratio score represents proximity to target (1) – precision, the deviation score represents how much the participant is off target – accuracy. A second subjective-objective ratio is calculated for the time reproduction task (TRT), called the duration.
judgement ($DJ$) (e.g. Hurks & Hendriksen, 2011). The task and duration judgement ratios are added in a linear regression model. Recall that optimal state motivation is characterized by a sense of “time flying away”. By constructing a time based index of state motivation, perhaps state motivation could be measured:

\[
State \ motivation = \beta_0 + \beta_1 TOT_{Ratio} + \beta_2 DJ_{Ratio} + \epsilon
\]

To avoid the error of averages of averages, average of composite scores were computed thus:

\[
\text{Average TRT (s)} = \frac{TRT10 + TRT12 + TRT14}{10 + 12 + 14} \text{ (s)}
\]

The average time flies ratio was calculated similarly to the average TRT, but was transformed: $avgTRTratio^{-1}$. For some of the calculations with the average TRT ratio values exceeding one were folded back into the distribution, resulting in an absolute measure of deviation were 1 represents perfect accuracy (see Figure 3). For example, 1.09 was transformed to $1-0.09 = 0.91$. Other time perception measures did not require folding as they all underestimated the objective time.

**Motivation.** The reasons behind using the state motivation index are 1) the previous lack of an objective correlate in the literature, which only asked whether participants experienced time passing faster (e.g. the questionnaire for current motivation, QCM), and 2) the lack of taking into account individual differences in time perception measures related to motivation (see Vollmeyer & Rheinberg, 2006).

After completion of all games, measures of intrinsic motivation were recorded using a Likert item style questionnaire (Appendix E), which is based on the intrinsic motivation
inventory (IMI) (Ryan, 1982) and in-house questions. The measures include competence, enjoyment (valuing), and task value for self versus peers. In the goal orientation literature, the latter contrast is also known as mastery versus performance. Task complexity is closely associated with optimal state motivation (flow) and competence. However, the current study does not consider anxiety.
Figure 3. The average TRT ratio paired with WM performance after folding in the data points above 1. Note the resulting higher density of data points proximate to 1.

Data Analysis

Statistical analysis was performed in SPSS 20.0.0 unless noted otherwise.

Distribution checks and outlier detection. Although there were more females than males in each age group, binomial tests showed that females and males were equally distributed both overall and per age group. Normality checks were performed using measures of skewness and kurtosis. All variables were subject to univariate outlier checks using P-P probability graphs together with the measure of skewness. Skewness and kurtosis for n-back
partial scores that constitute the composite n-back performance score were not considered, because the composite score was normally distributed.

Kolmogorov-Smirnoff (K-S) tests confirmed the measures of skewness. In addition, several measures were significantly non-normal ($p<0.05$): all game preference ratings, pre-ratings of ease of task and difficulty, post ratings of monotonicity and challenge, subjective time on task for the VDL and the n-back, time experienced flying on the CWM, the SMP score, and IMI measures: performance competence, self value, effort, and enjoyment. Among the questionnaire items, the post rating of fun and boredom were skewed toward more fun and less boredom.

Most of the objective time on task measures were skewed compared to a normal distribution. A Weibull distribution appeared to provide a better fit for these frequencies (Weibull distributions are used in reliability engineering to describe time to failure). However, because the composite TOT ratio was approximately normally distributed, the partial values were not transformed. The normality checks were also used for univariate outlier detection. Outliers in the time reproduction task and the OOO were detected by centring around the median absolute deviation (MAD) (Wilcox, 2010) in R (R Development Core Team, 2009) with the cutoff at 2.5 (Rousseeuw and Hubert, 2011).

Two multivariate outliers were detected in CWM mirror score on a Tukey boxplot in age group 6-7. Five additional multivariate outliers were detected when boxplotting against high/low (median split) TRT ratio at 12s. All mirror score outliers were Winsorized, prior to correlations for average time flies. For correlations where age was controlled for, multivariate outlier detection was performed using Mahalanobis distances as described in Tabachnick & Fidell (2007).
Results

Several of the initial predictions did not hold and some of their premises needed re-examination. For example, taking individual differences in time perception into account did not improve the state motivation measurements. Next, it will be shown that the various measures of time perception reflects different constructs, but first we turn to a few descriptives.

Descriptives

Table 1 displays the means and standard deviations for performance in the games and tasks. Table 2 describes the time perception measures averaged across games or the three TRT conditions. Table 3 describes game preferences, where the latest game under development appears to be the preferred game.
Table 1. Mean scores for the different games and tasks. Note the increasing trend on all scores.

<table>
<thead>
<tr>
<th></th>
<th>CWM</th>
<th>CWM Mirror</th>
<th>VDL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Age 6-7</td>
<td>6.25 (2.01)</td>
<td>28.15 (2.48)</td>
<td>9.54 (.97)</td>
</tr>
<tr>
<td>Age 8-9</td>
<td>8.82 (3.32)</td>
<td>32.86 (9.13)</td>
<td>10.95 (1.46)</td>
</tr>
<tr>
<td>Age 10-11</td>
<td>9.67 (2.65)</td>
<td>35.22 (8.26)</td>
<td>11.44 (1.42)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>SMP</th>
<th>n-back</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Age 6-7</td>
<td>6.54 (1.33)</td>
<td>.85 (.36)</td>
</tr>
<tr>
<td>Age 8-9</td>
<td>7.45 (2.15)</td>
<td>.88 (.29)</td>
</tr>
<tr>
<td>Age 10-11</td>
<td>10.22 (2.64)</td>
<td>1.16 (.15)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>OOO (WM)</th>
<th>Maths</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Age 6-7</td>
<td>6.08 (2.02)</td>
<td>3.25 (3.70)</td>
</tr>
<tr>
<td>Age 8-9</td>
<td>7.95 (2.44)</td>
<td>7.73 (3.68)</td>
</tr>
<tr>
<td>Age 10-11</td>
<td>11.57 (2.37)</td>
<td>11.33 (2.69)</td>
</tr>
</tbody>
</table>
Table 2. Mean values and standard deviations for the different averages of the three time perception measures. Note the overlapping standard deviations.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Average TRT Ratio Mean (SD)</th>
<th>Average TOT Ratio Mean (SD)</th>
<th>Average Time Flies (QCM) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age 6-7</td>
<td>.74 (.21)</td>
<td>.02 (.01)</td>
<td>3.00 (1.01)</td>
</tr>
<tr>
<td>Age 8-9</td>
<td>.78 (.21)</td>
<td>.03 (.01)</td>
<td>3.60 (1.29)</td>
</tr>
<tr>
<td>Age 10-11</td>
<td>.86 (.22)</td>
<td>.02 (.01)</td>
<td>3.64 (1.25)</td>
</tr>
</tbody>
</table>
Table 3. Game preferences across age groups. Numbers represent first choice.

<table>
<thead>
<tr>
<th>Age group</th>
<th>CWM</th>
<th>VDL</th>
<th>SMP</th>
<th>n-back</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-7*</td>
<td>0</td>
<td>1</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>8-9*</td>
<td>2</td>
<td>3</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>10-11</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>

* One missing data point

Working Memory Performance

Working memory (WM) performance, as measured on the odd one out (OOO) task, correlated with the average TRT ratio (i.e. time perception accuracy), $r=0.404$, $p=0.037$, when age group and sex was partialled out. (The correlation, however, would have been stronger without partialling out age and sex, $r=0.515$, $p=0.004$.) All game scores correlated with WM, as well as maths and TRT ratio at 12 s. The correlations are listed in Table 4.

The average TOT ratio, the state motivation measure, correlated with WM, $r=0.330$, $p=0.043$, only when controlling for age. The effect size of this correlation was relatively large in the 10-11 year olds, $r=0.729$, $p=0.040$, but absent in other age groups. After imputation of four missing values (Appendix A), the correlation became non-significant, $r=0.080$, $p=0.638$. However, the TOT ratio only refers to accuracy (data points being nearby the target). When measuring precision (the density of a data cluster, despite being off-target) the deviation of the subjective TOT from the objective TOT can be used as a measure, which proved to be significant; see Figure 4 for a tentative model of the relationship between time perception measures and WM.
Table 4. Significant correlations between WM and: game outcomes, math outcome, TRT ratio at 12s; but not TOT ratio.

<table>
<thead>
<tr>
<th>Pooled correlations†</th>
<th>CWM Score (Primary memory)</th>
<th>CWM Mirror Score (Secondary memory)</th>
<th>VDL Score</th>
<th>Maths Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>OOO Performance (WM)</td>
<td>.495**</td>
<td>.382*</td>
<td>.409*</td>
<td>.485**</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>.020</td>
<td>.016</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SMP Score</td>
<td></td>
<td>n-back Performance</td>
<td>Winsorized TRT Ratio 12s</td>
<td>Average TOT Ratio</td>
</tr>
<tr>
<td>OOO Performance (WM)</td>
<td>.555**</td>
<td>.369*</td>
<td>.357*</td>
<td>.080</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>.029</td>
<td>.028</td>
<td>.638 (ns)</td>
</tr>
</tbody>
</table>

† 10 imputations, 10000 iterations; Sex and age have been partialled out.
Figure 4. Sketching out a Time-WM model. Age and sex were partialled out in all correlations. The correlations suggest that different aspects of WM capacity correlate with different types of time measures (TOT, TRT, time flying). \textit{ns} denotes non-significant.

**Toward a Time Perception–WM Model**

TRT ratio at 12s correlates with CWM mirror score (SM), $r=0.318$, $p=0.043$ (Figure 4). When cross-validating and splitting by age group, the TRT ratio at 12s only correlated with the CWM mirror score (with sex still partialled out) in 10-11 year olds, but strongly, $r=0.716$, $p=0.046$. However, there were only 6 valid cases in this age group, so caution should be taken in the interpretation of this relationship. Furthermore, the correlation between CWM time flies and CWM score was not found in any of the age groups.

Whereas the only time perception measure to correlate with the CWM score (PM) was the deviation (i.e. precision) of the subjective duration judgement from the objective time
on task (TOT), the CWM mirror score (SM) correlated with several time perception measures. Correlations are reported in Figure 4.

The different correlations for time fly CWM and the overall time fly average is probably due to the differences between the distributions, paired \( t(43)=2.055, p=0.046 \). The average was more centred around the 7-point Likert median, mean = 3.4 (1.2) than the CWM, mean=3.0 (2).

Apart from the CWM mirror score, of all the game and task scores only OOO performance correlated with the TRT ratio at 12s, \( r=0.337, p=0.045 \). Further support for correlations of TRT ratio at 12s with PM are shown by the correlations with the n-back component scores: correct omissions, \( r=0.478, p=0.002 \), and false alarms, \( r=-.329, p=0.038 \), but not other n-back components.

**Motivation Outcomes**

Overall, initial motivation neither predicted working memory performance on the OOO task, nor state motivation. However, the prospect of having Fun predicted scores on the Maths test, with age partialled out (Table 4), \( R^2=0.311, F(2,40)=9.040, p=0.001 \), although Fun barely made it into the equation, \( t(42)=2.062, p=0.046 \). See Table 5. (Cross-validation of the model using an 80/20-split failed. However, the cross-validation did not use a stratified sampling procedure. Given the low \( n \), this procedure faces difficulties.) Furthermore, state motivation did not moderate or mediate maths performance, when partialling out age and sex. Pre-motivation measures Easy but not Difficult predicted the game outcome for only one game (VDL), but because the reverse measure Difficult is intended to validate Easy the results are inconclusive. Game outcomes and Maths scores did not correlate with either measure of state motivation (TOT ratio, QCM). However, maths scores correlated with some of the intrinsic measures (Table 6). (No correction for multiple comparisons were made. The
less significant correlations of mastery and performance should therefore be carefully considered.)

Table 5. The prospect of having Fun predicted scores on the Maths test. A stepwise regression is shown. (Because of the low n, confidence intervals are not shown.)

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.488*</td>
<td>.238</td>
<td>.220</td>
<td>3.95018</td>
</tr>
<tr>
<td>2</td>
<td>.558b</td>
<td>.311</td>
<td>.277</td>
<td>3.80229</td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), Age group
b. Predictors: (Constant), Age group, Pre fun

d. **ANOVA**

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Regression</td>
<td>1</td>
<td>199.915</td>
<td>12.812</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>41</td>
<td>15.604</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>42</td>
<td>839.674</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Regression</td>
<td>2</td>
<td>130.690</td>
<td>9.040</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>40</td>
<td>14.457</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>42</td>
<td>839.674</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Dependent Variable: MATHS_score
b. Predictors: (Constant), Age group
c. Predictors: (Constant), Age group, Pre fun

d. **Coefficients**

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std Error</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Constant)</td>
<td>5.651</td>
</tr>
<tr>
<td></td>
<td>Age group</td>
<td>.006</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Constant)</td>
<td>-1.607</td>
</tr>
<tr>
<td></td>
<td>Age group</td>
<td>.007</td>
</tr>
<tr>
<td></td>
<td>Pre fun</td>
<td>1.630</td>
</tr>
</tbody>
</table>

a. Dependent Variable: MATHS_score
Table 6. Significant correlations between Maths scores and IMI measures.

<table>
<thead>
<tr>
<th>Control Variables</th>
<th>Mastery (IMI)</th>
<th>Performance (IMI)</th>
<th>Post Enjoyment (IMI)</th>
<th>Effort (IMI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex &amp; Age group</td>
<td>Correlation</td>
<td>.363</td>
<td>.509</td>
<td>.380</td>
</tr>
<tr>
<td>Maths Score</td>
<td>Significance</td>
<td>.021</td>
<td>.001</td>
<td>.016</td>
</tr>
<tr>
<td></td>
<td>(2-tailed)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>38</td>
<td>38</td>
<td>38</td>
<td>38</td>
</tr>
</tbody>
</table>

We reduced the IMI items using principal components analysis (PCA) (see Jaeggi et al., 2011). Here we used varimax rotation and confirmed the number of components using both the elbow test in the scree plot and the Kaiser criterion. The resulting factor scores were also included in the analyses. The resulting factors loadings suggested two components: performance/peer-oriented motivation (1) and (2) mastery/self oriented motivation. See Table 7. There is only a slight cross-loading on mastery (i.e. it is above 0.400).
Discussion

The current study sought to evaluate measures of motivation in the context of working memory training, using time perception as an implicit motivation construct, and to investigate the link between working memory and time perception, while controlling for motivation. Although the generalizability of the findings is limited, the results align with several previous studies. The main limitation is a low statistical sensitivity due to the low sample size. Interpretation of null findings should be carefully considered, as the study might have failed to detect correlations with low effect sizes. The main strength is that correlations were found despite low power.

The Time Flying Construct might not Capture State Motivation

The current study is – to our knowledge – the first to evaluate an implicit measure of motivation that compares a subjective experience of time passing to a factual objective state of affairs: time on task. However, the time reproduction task (TRT) appears to be difficult to use in capturing state motivation. This conclusion rests on the reliability and validity of the
classical motivation measures of the current study, suggesting that further work is encouraged where motivation is explicitly manipulated while controlling for coordinative capacity.

The results indicate that time does not necessarily fly when having fun. Rather, time perception accuracy appears to have a stronger link to working memory capacity (see also Woerhle & Magliano, 2012) than motivation. This finding is consistent with the view that time constraints are more relevant for executive control than for motivation, as evidenced in studies on executive control depletion over time, while controlling for motivation (Schmiechel, 2007). Although a null finding, the absence of a correlation between motivation and both measures of the experience of time flying does not exempt the view of an inverse causal relationship: people who are lured into believing that time passed faster report greater enjoyment compared to those who were provided the accurate time (Sackett et al., 2010). Sackett and colleagues concluded that belief in time flying faster is merely a suggestive folkpsychological construct.

Two of the main limitations of the study include the limits characteristic of pre/post designs and the absence of a measure of motivation after each game, which has previously been validated. The reason behind using an implicit motivation measure was to avoid asking the same questions repeatedly for each game, which might have resulted in a change of intrinsic motivation or performance. In the current study, participants needed not answer Are you enjoying this? or Are you bored? four times in a row. The implicit measure was designed with this in mind. In addition, because the indirect questions did not enhance reflections on the participants’ motivational state in the sequential presentation, it is possible that experimenter-dependent evaluation apprehension was further minimized.

In contrast to the IMI questionnaire items, the current state motivation questions are not directly related to any affective quality of the participants' experience, but to a cognitive
quality: time perception. In their model of self-regulation and intrinsic interest Sansone and Harackiewicz (1996, p.208) suggested that when subjects evaluate their progress and the distance left to achievement they might readjust their behaviour. From a theoretical perspective, it was thus critical to avoid introducing an opportunity for participants to directly evaluate their affective experience of the games. Hence, appraisals of the game experience were postponed to a post-test for the overall procedure. To compare the subjective TOT with the question in QCM (Vollmeyer & Rheinberg, 2006), we asked whether time was flying or not.

A more general justification for including a new implicit measure was to partially avoid the, otherwise well-found, criticism of the absence of control groups (non sic!). It has been suggested that traditional pre/post test designs in the contexts of developmental approaches (Solomon & Lessac, 1968) and transfers between tests within paradigms (Solomon, 1949) are incomplete in as far as they do not take into account the test effects of the test administration; the remedy is to have three control groups: group I receives pre- and post-tests without the intermediate training, group II receives training and post-test only without pre-test, and group III receives training and post-test only without pre-test (Solomon, 1949). Admittedly, such studies place high demands on sample size, but more rigorously address the instrumental validity of measures. The questions on state motivation in the current study were administered post each game. The Solomon four-group design does not address the influence of repeated post-tests, as the post-test are administered to all four groups. In a developmental training context where transfer between tasks is often emphasized (e.g. Bergman-Nutley et al., 2009; Shipstead et al., 2012) it is important to also acknowledge the possibility of transfer within tasks, especially when the items involved correlate with each other and might influence each other over time.
Perhaps participants with low time perception accuracy are more easily distracted, which results in a time perception failure and thus higher “state motivation”. This would further suggest that time flying does not always reflect enjoyment or motivation, but may reflect performance failure due to high coordinative processing demands, in a similar vein of depletion studies – as both views concern constraints of coordinating resources, either in sequential shifts (e.g. task-switching, rule-shifting) or during simultaneous processing (e.g. dual-tasking, multiple choice).

The current study was unable to prove a link between state motivation and performance. It is questionable that the QCM questionnaire items as well as the TOT ratio reflect state motivation or flow. Rather, these measures correspond to the time perception construct. Nevertheless, time perception can be operationalised in different ways, and these different operationalisations appear to reflect different aspects of working memory. More research is needed to validate the tentative model presented here (Figure 4). However, the evidence from correlations with the secondary CWM task components of the CWM, the n-back, and the OOO suggests a clear association between time reproduction and coordinative capacity. Simultaneously, although providing vague inference, the TOT deviation (i.e. accuracy) score correlates with primary CWM task. The results suggest that the time flies question (i.e. the precision score) of the QCM measures properties related to coordination in WM or WM encoding function. They may not be related to state motivation at all. However, caution should be exercised in interpreting this null finding.

In the absence of opposing correlations, these results, when juxtaposed, suggest a double dissociation on the cognitive level of explanation between (1) secondary CWM task with TRT and Time flying, versus (2) primary CWM task with TOT deviation. In extension, these results support a distinction between two working memory dimensions. Whereas the TRT and Time flying measures emphasise retrospective retrieval, TOT deviation might
reflect the encoding process more than it reflects retrieval. From this perspective, the PM-SM distinction becomes redundant as no further memory faculty needs to be postulated. However, the possibility remains that there exists a store, which maintains goals/task-sets/rules separately from working memory (Logan, 2004; Bengtsson et al., 2009). Further studies need to investigate the relationship between the classical retrieval-encoding distinction within working memory, the more recent primary PM/SM distinction, the coordinative/sequential distinction, and the storage of goal processes (e.g. “prospective memory” or rule-setting) in more detail.

Although the variance of self-regulation is important within individuals from time to time, self-regulation relies on accurate self-knowledge. Thus, individual differences in future between-subjects analyses could test whether competence correlates with coordinative working memory capacity, and thus achieve a measure of self-knowledge (i.e. accuracy of competence). Time perception measures are inadequate measures of motivation because they rely upon coordinative working memory capacity, unless researchers partial out this component and take causal attribution (cf. Sackett et al., 2010) into account.

On the account of these findings, optimal state motivation or flow experience appears to be a questionable construct. However, it is still possible that these experiences are real and do occur, but perhaps more rarely than was previously held. It remains to be investigated whether proneness to flow experiences (e.g. Klasen et al., 2011) is related to individual differences in working memory capacity or executive control. In addition, game preference was overwhelmingly positive for SMP, suggesting that the current development efforts are in the right direction.
Multiple Goal Reconfigurations Offset Time Perception Accuracy

The inability of the time reproduction task to reliably replicate findings for any other interval than twelve seconds could be explained due to its administration at the very end of all game trials (Figure 1). Because there was no change in motivation between pre and post-test scores, depletion of executive control could be the main factor, as have been found in studies controlling for motivation (Schmechel, 2007). From this perspective it is surprising that performance on the twelve second interval procedure was reliable. It is possible that the fixed task order could serve as an explanation. After a brief practice round using much shorter intervals, possibly triggering correlates of sub-second intervals rather than super-second intervals (cf. Wiener et al., 2011) the participants had to switch tasks – or execute goal reconfiguration. The switching of tasks, or goals, is associated with processing costs and temporarily slows down performance (Logan, 2004). Thus, responses are expected to be unreliable during the first interval, and lack uniformity possibly due to high variance of default executive control capacity (either attention or working memory capacity), time-bound depletion capacity (i.e. coordinative capacity), or distractibility – the ability to cope with distractions with minimal processing cost. An alternative explanation would suggest that participants adopted a low-effort strategy (Hockey & Earle, 2006). The unreliable results on the fourteen second task could be due to the increased variance that is associated with greater intervals (speculatively suggesting a fine line between 12 and 14 seconds). The current study lacked a randomisation protocol for the time reproduction task, however surprisingly, the 12 second interval appears to be a robust testing interval (cf. Espinosa-Fernández et al., 2004; Gautier & Droit-Volet, 2002; Hwang et al., 2010) following a task switch.

The administration of the TRT task at the end of the ~40 minute session may have resulted in an executive depletion effect. Previous research found elongated subjective time estimates of time spent on tasks subsequent to executive depletion independent of executive
modality: after tasks involving emotion regulation, reading aloud, and holding one’s breath (Vohs & Schmichel, 2003). This might partially explain why the current reproduction intervals were contracted. In ADHD, the temporal span of working memory appears to be shorter than in controls, resulting in contracted time when subjects attempt to synchronise their drumming with a slow metronome beat (Gilden & Marusich, 2009). One possible departure for future studies is to control for executive depletion, for example by taking into account the day time and how many working or school hours have passed for participants, or to measure rhythmical performance. A large study (n=247, ages 6-25) found that having practised a musical instrument improves visuospatial working memory (Bergman Nutley & Klingberg, 2011). Possibly, these findings could be partially accounted for due to rhythmical training.

One possible explanation for poor time accuracy is impatience. On this assumption, impatient participants had trouble changing focus, while patient participants were more distractible (i.e. had the ability to cope with distractions) in the working memory domain. However, time perception accuracy findings in children with ADHD vary between overestimation and underestimation in duration judgements, suggesting a more complex role of impatience or impulsivity (Sonuga-Barke et al. 1998).

**Further Limitations**

One strength of the current study is that motivation is controlled for using multiple measures. However, there is one downside of only administering previously validated measures of motivation (e.g. the IMI) subsequent to the complete session of game trials. One particular difficulty with pre-validated measures of motivation, such as the IMI, is the context in which their reliability was developed. The current study found an association between motivation and maths, but not with the working memory “games”. An alternative explanation
of this finding would suggest that the children were primed for the familiar maths task but had fewer preconceptions about the games. However, the absence of a difference between pre and post test motivation measures points in the opposite direction, suggesting a lesser role of task familiarity for motivation. Traditional measures of motivation appear to have remained stable throughout the session.

The results differ from a previous study that established a link between the experience of time flying and intrinsic motivation. The cited study suffered from low effect sizes and did not consider the magnitude prior to concluding the implications of the findings (Conti, 2001). Furthermore, the study used a different measure of time perception in an experience sampling protocol: time awareness as the deviation of clock time estimation from the actual time. The author concluded that Cronbach’s alpha = 0.64 was adequate. However, scores below 0.7 are questionable (Field, 2009), suggesting that the questionnaire items related to the experience of time produced inconsistent results. These limitations might explain the deviation from the current results.

In a retrospective sensitivity analysis for correlations (with the parameters $\alpha=0.05$, power=0.80, n=44) the detectable effect size was calculated to 0.397 (using G*Power 3.1.0; Faul, Erdfelder, Lang, & Buchner, 2007). A second analysis was carried out accounting for sample size attrition in some parts of the study ($\alpha=0.05$, power=0.80, n=38) resulting in the detectable effect size: 0.423. Several of the correlations in the current study were detected despite low power (see Appendix F: Sensitivity analysis). However, the low sensitivity also implies that correlations with small effect sizes were possibly not found, which might account for some of the differences from the previous literature, including the absence of several correlations with intrinsic motivation, and possibly also the lesser reliability of the TRT task. The null findings in the current study should be carefully considered.
The findings tentatively suggest that time reproduction tasks, which are administered after an approximately 40 minute working memory training session, do not capture the motivation construct in children aged 6-11 years old at Swedish public schools. The study only investigated participants in matched groups from a single school, although with three different teachers, which warrants further caution in generalizing the results. The results may not replicate in adolescents and adults. Furthermore, depletion of executive control and task switch processing costs should be taken into account when administering tasks that tax working memory. Motivation related to working memory training has mainly focused on task-specific motivation – that is: the intrinsic motivational properties of games, which are reflected in game preferences. Although guidelines for future design of applications are important, an understanding of motivational processes is difficult to achieve without a focus on individual mechanisms, including state and systems motivation. In addition, the current game measures only give a relative performance view, in the absence of a standardised index.

In a previous study (Jaeggi et al., 2011) it is possible that using smileys in a motivation questionnaire produced biased responses, because a neutral face, which often serves as a midpoint on such scales, is perceived more negatively than calm faces (Tottenham et al., 2009). Furthermore, it is not entirely clear whether perceived difficulty can be represented by a facial expression. Nevertheless, children do prefer Likert scales over visual analog scales (VAS), which they also find easier to complete (van Laerhoven, van der Zaag-Loonen, & Derkx, 2004). However, children may express “end-aversion bias” and avoid extreme responses, which are noticeable when scales are short (i.e. 5 items or below) (van Laerhoven et al., 2004). The current study avoided smileys and used longer Likert scales instead of VAS.

Furthermore, the scope of the current study was working memory training tasks. Because the OOO is traditionally not used as a training task, but as a “pure” and reliable (see
Alloway et al., 2006) outcome measure, time perception questions were not administered for the OOO task. Instead, OOO performance was compared with the average TOT ratio of the working memory games. A chief limitation was the administration of the time tasks in children age 6. Future studies may use time bisection tasks with pretraining for a more valid measure (e.g. Droit-Volet, Tourret, & Wearden, 2004).

Concerning the data analysis, less sophisticated statistical procedures were selected, for example the outlier detection protocol, due to time constraints (the more advanced techniques are statistically more robust – see Wilcox, 2010 – but their application were in large due to the educational context of the MSc rather than methodological concerns peculiar to the current design).

**Further Implications**

If the correlations between coordinative performance and time perception are bidirectional, we would predict that training on a time reproduction task at 12s, or some psychophysically adaptive version thereof would improve the secondary CWM task component of working memory. If the opposite causal direction holds, then training tasks with secondary CWM task components such as the OOO and the CWM would improve TRT performance at 12s. A future study could test this using an active control group to establish the causal link between time reproduction and the secondary CWM task component of working memory. (However, depletion must be controlled for.) If temporal cues underlie time perception and if it is possible to train coordinative working memory, rather than sequential – i.e. to manipulate the number of simultaneously presented properties rather than the number of units presented through time (span) – a reasonable prediction follows: successful training of coordinative working memory capacity would lead to more accurate time perception when performing simpler sequential tasks.
It is important to note that motivation measures do not necessarily capture self-regulation that is dependent on resource allocation. Time perception measures might better reflect changes in self-regulation. For optimal results on working memory training tasks, future studies may combine working memory training with self-regulation training (Muraven, Baumeister, & Tice, 1999; Oaten & Cheng, 2006) and motivational reframing (Autin & Croizet, 2012). The prediction is that if the time perception ability can somehow be trained to make time passing appear faster in, for example, children with ADHD, participants’ depletion would set in later, leading to more sustained performance.

The overall results call the instrumental validity of state motivation as measured by the QCM into question. It remains to be seen whether the different time perception measures correlate with different neural correlates in both ADHD populations and healthy controls.

Several factors have been implicated to affect performance on working memory tasks: task difficulty (e.g. Dutke, 2005), motivation (e.g. Choi, Fiszdon, & Medalia, 2010), executive control resources (Logan, 2004), monitoring style (Savine et al., 2012), and the presence of conflicting goals (Simon, 1967). The perhaps most curious result was the absence of performance correlations with motivation. How the motivation construct can be reliably and validly measured might be a deciding question for future studies.

**Implications for applied working memory training.** Under the assumption that working memory and time perception in ADHD represent the mere extremes of natural population variance, the current study was unable to establish a link between working memory and time perception. One might be tempted to conclude that ADHD is not driven by a single common mechanism. However, because of the complex nature of dopamine such a conclusion cannot be ruled out.
Given the perspective from resource depletion, task-switching costs, and sequential coordination, an alternative explanation for the efficiency of working memory capacity training in ADHD would suggest a latent learning mechanism: the training targets the ability to cope with distractions – distractibility – by attentional demands, rather than sequential “capacity stretching”. Future studies may focus on the contribution of cognitive distractors to training benefits in controlled environments. Instead of adjusting the dose-response relationship by increasing the working memory span, the span can be kept constant, while experimenters gradually increase the level of cognitive interruptions. The capacity to successfully cope with distractions (causing mere interrupts) instead of failing to attend to distractors (causing disrupts), can be tested using a systems motivation model in which either the interrupt process or the notice process (refocusing) is subject to failure (see Simon, 1967). Possible explanations to the current findings include: 1) the working memory capacity becomes taxed by task-irrelevant distractors, suggesting an error due to limited capacity of the episodic buffer 2) the episodic buffer is not emptied - or refreshed - sufficiently fast enough, suggesting an error in the task refocusing process.

If ADHD is associated with a deficient coordinative working memory capacity, one might expect that difficulties in the ADHD population exist in situations where high demands are placed on coordination. One such example is the establishment of social bonds through social coordination dynamics (see Oullier, de Guzman, Jantzen, Lagarde, & Scott Kelso, 2008). Indeed, ADHD is associated with peer problems (for a review see McQuade & Hoza, 2008). Future studies are needed, which compare effects of coordinative versus sequential training, and the interaction of both. In addition, social coordination outcomes could be gathered after cognitive coordinative training.

Motivation, perceiving value, and two types of feedback. Intrinsic motivation did not correlate with state motivation. However, various components of motivation could still be
distinguished. The factor analysis suggests that motivation associated with peer comparisons – performance motivation – is further associated with enjoyment and effort. These results suggest that children's motivation was extrinsically driven by peer comparison if they did not find the task to be valuable. Those who did find the task valuable aimed to increase their skills. However, they did not enjoy it as much. Perhaps this is due to that they found the task to be easy, as they to a lesser degree reported that they exerted their effort. Those who saw the value of the tasks, did perhaps not treat the tasks as games, while does who saw less value in the tasks, turned the tasks into a sport, against their imagined or real competitors. If this holds true, competitive children turn boring working memory tasks into games, while children who value and appreciate working memory tasks intrinsically focus on their own performance improvement. The implication for design is two-fold: younger children and otherwise children who have difficulties of comprehension are expected to gain more from competitive games, where comparisons are made with peers. In contrast, players who are introduced with a thorough understanding of playing the games – the meaningful consequences of this action – would benefit from feedback on their own performance. Future games could incorporate a video or presentation in which the value of working memory training is explained. Based on a questionnaire following the presentation, multiple choice questions would then categorise players into either "performers" or "masters" depending on whether they grasp the value of training or not. Feedback in the program would then be decided upon the results of the questionnaire: either peer performance or self-related mastery feedback would be provided. By using such a questionnaire to match groups into performers and masters, a mismatch condition in a future experiment could test how feedback-matching affects performance, thereby testing these predictions for optimizing working memory training.
From a systems motivation perspective that emphasises that goals are achieved within certain time-constraints (Simon, 1967), due to the conjunction of time perception deficits with motivation deficits in ADHD, one might speculate whether problems with processing within time-constraints might explain reports of poor motivation in ADHD.

**Time perception accuracy relies on coordinative capacity.** The high performers on the intervening mirror task of the CWM task were more accurate in reproducing time on the separate TRT task, while also having a faster average time flying experience. Low working memory capacity is associated with more accurate time perception in conjunction with working memory tasks (Woerhle & Magliano, 2012). However, this suggests that participants with high sequential working memory capacity should achieve better on the isolated time perception task, the TRT, than participants with low capacity (i.e. with lower scores on the primary task). However, there was no association between participants with high scores on the primary task and time reproduction ability on the isolated task. These results when taken together suggest that accuracy of time perception is not driven by sequential capacity per se, but rather the capacity to switch attention to a secondary task. Possibly, there is one underlying process common to both attention shifting between tasks and the cognitive processing of temporal cues. For example, tracking the temporal cues given by a ticking clock requires shifts in attention between ticks rather than an extensive sequential working memory capacity for storing the cues in a stack. The current results align with the following statement: given the task-switch cost as witnessed in response time delays (e.g. Logan, 2004), switching from one temporal cue to the next (cf. Liverence & Scholl, 2012) requires coordinative capacity, and possibly only to a lesser extent sequential capacity.
Acknowledgements

Thanks to Judith Annett for constructive feedback on a previous version of the manuscript. I am grateful to Sissela Bergman Nutley, Mariama Dampha, Jonas Beckeman, Cogmed, Sakari Kallio, and Torkel Klingberg. TK and SBN initiated the research question and had the main responsibility for the study. TK focused the task, distributed resources and followed up on the realization of the study. SBN was project manager for DL, MD and JB. SK gave feedback on the written report. DL produced the predictive sub-hypotheses, the time schedule, executed the literature review, designed the study, authored the information letter and questionnaire, performed the randomization, decided sampling strategy and recruited participants through principals, teachers, and parents; programmed the time reproduction task, assisted the data gathering on site, planed and programmed the data analysis, summarized and analyzed all data and wrote the report. SBN, DL and MD developed the pre-game mirror task. DL, SBN and JB developed the algorithm for the $n$-back task. JB programmed the $n$-back task and the working memory disruption task, created a unified presentation of the applications, and administered the server. Cogmed contributed with software and a server for running the procedure and storage of raw data. MD was the lead experimenter and gathered data from all participants. DL would like to thank all the members of the Developmental Cognitive Neuroscience Lab at the Karolinska Institute for their feedback, in particular Megan Spencer-Smith, as well as the school: the principal, teachers, parents, and the children who participated.
References


behavior (pp. 100–109). Heidelberg: Springer. (Secondary source. See Publication manual of the American psychological association, 2010)


Appendix A: Missing data

For the overall analysis, three cases were excluded list-wise: one participant had difficulties understanding the instructions and wished to abort; technical difficulties with the experimental setup occurred while gathering data from two participants, resulting in slower task presentation. For the analysis of the time reproduction task (TRT) only, three cases were excluded list-wise: one participant counted aloud and the other two were excluded due to the reasons mentioned above.

Early accidental responses during the TRT were treated as outliers and the data was Winsorized (Wilcox, 2010): TRT10s (4.5%), TRT12s (6.8%), TRT14s (18.2%). Data (9%) was imputed using multiple imputations for the performance on the OOO task, using age (months), sex and the winsorized TRT ratios, in a linear regression model, with fully conditional specification option selected, including two-way interaction effects, running 10 data sets with 10000 iterations each.
Appendix B: Time reproduction task code

//Time Reproduction Task
//Programmed by Daniel Labbé 2012

Experiment() {

    Context() {

        AssignmentGroup() {

            SubjectCode = "Output.txt";
            ExperimentName = "Time Reproduction";
            RandomizeTrials = 0;
            DataFileName = "%SubjectCode%";
            DataFileTrialFormat = "%Trial.SimpleDisk:Left_2ON.Duration% %Trial.SimpleDisk:Right_4ON.ResponseTime%";

        }

    }

    Session() {

        Instruction() {

            Text = ["Träffa tiden",
                    " ",
                    "På skärmen visas det två lampor. Den till vänster kommer att lysa av sig självt, men"]

        }

    }

}
den till höger kan du tända själv. Först får datorn den
vänstra lampan att lyssa. När den slutar lyssa, så kan du tända
din egen lampa.

" "

"Kan du få din lampa att lyssa
lika länge som datorns lampa? Håll nere den långa tangenten
lika länge som den första lampan lyste.

" "

"(Tryck på en tangent för att
fortsätta.)"};

}

SessionEnd() {
    SessionEndMessage();
}

Trial(TrialCounter, SimpleDisk:Left_2ON.Duration){

//First frame
Message() {
    Timer = de.pxlab.pxl.TimerCodes.NO_TIMER;
    Text = ["Vänta..."];
    LocationX = -100;
    LocationY = -75;
SimpleDisk:Left_1OFF() {
    Timer =
    de.pxlab.pxl.TimerCodes.RAW_CLOCK_TIMER;
    Overlay = de.pxlab.pxl.OverlayCodes.JOIN;
    Color = Gray;
    Size = 100;
    LocationX = -100;
    LocationY = 0;
}

SimpleDisk:Right_1OFF() {
    Timer =
    de.pxlab.pxl.TimerCodes.RAW_CLOCK_TIMER;
    Duration = 2000; //Frame duration: WAIT
    Overlay = de.pxlab.pxl.OverlayCodes.JOIN;
    Color = Gray;
    Size = 100;
    LocationX = 100;
    LocationY = 0;
}

//Next frame
SimpleDisk:Right_2OFF() {
    Timer = de.pxlab.pxl.TimerCodes.NO_TIMER;
Color = Gray;
Size = 100;
LocationX = 100;
LocationY = 0;

SimpleDisk:Left_2ON() {
    Timer = de.pxlab.pxl.TimerCodes.RAW_CLOCK_TIMER; //Timer set by trial
    Overlay = de.pxlab.pxl.OverlayCodes.JOIN;
    Color = Yellow;
    Size = 100;
    LocationX = -100;
    LocationY = 0;
}

//Next frame

SimpleDisk:Left_3OFF() {
    Timer = de.pxlab.pxl.TimerCodes.NO_TIMER;
    Color = Gray;
    Size = 100;
    LocationX = -100;
    LocationY = 0;
}

SimpleDisk:Right_3OFF() {

Timer =

de.pxlab.pxl.TimerCodes.LIMITED_RESPONSE_TIMER;

Duration = 20000;
Overlay = de.pxlab.pxl.OverlayCodes.JOIN;
Color = Gray;
Size = 100;
LocationX = 100;
LocationY = 0;

//Next frame

SimpleDisk:Left_4OFF() { 

    Timer = de.pxlab.pxl.TimerCodes.NO_TIMER;
    Color = Gray;
    Size = 100;
    LocationX = -100;
    LocationY = 0;

}

SimpleDisk:Right_4ON() {

    Timer = de.pxlab.pxl.TimerCodes.GO_TIMER | RELEASE_RESPONSE_TIMER;

    Overlay = de.pxlab.pxl.OverlayCodes.JOIN;
    Color = Yellow;
    Size = 100;
    LocationX = 100;
}
LocationY = 0;

} //Next frame

SimpleDisk:Left_5OFF() {
    Timer = de.pxl.TimerCodes.NO_TIMER;
    Color = Gray;
    Size = 100;
    LocationX = -100;
    LocationY = 0;
}

SimpleDisk:Right_5OFF() {
    Timer = de.pxl.TimerCodes.RAW_CLOCK_TIMER;
    Duration = 2000;
    Overlay = de.pxl.OverlayCodes.JOIN;
    Color = Gray;
    Size = 100;
    LocationX = 100;
    LocationY = 0;
}

Procedure() {

}
Session() {
    Block() {
        //Trial(Trialcounter, Lamp Duration); e.g.
        12000ms = 12 seconds
        Trial(1, 10000);
        Trial(2, 12000);
        Trial(3, 14000);
    }
}
Appendix C: Information letter

Information om deltagande i studie

Till våren startar en forskningsstudie om sambandet mellan motivation, arbetsminne och matematisk färdighet hos skolbarn. Arbetsminne är ett slags minne för tillfällig hantering av information. Till exempel använder vi arbetsminnet när vi försöker memorera ett telefonnummer eller lösa en matteuppgift med hjälp av huvudräkning.

Just nu söker vi deltagare i åldrarna 6, 8 eller 10, som kan tänka sig att spela särskilt framtagna arbetsminnesspel på en dator vid ett tillfälle i skolan. I anslutning kommer barnen få besvara några motivationsrelaterade frågor och räkna på ett räknetest. Undersökningen varar i cirka 40 minuter där barnet får träffa forskarassistent Mariama Dampha och magisterstudent Daniel Labbé.

Det är alltid möjligt att förbehållslöst dra sig ur studien och det är vid varje ögonblick upp till barnen själva om de vill delta eller inte. Samtliga deltagare kompenseras för den tid vi tar i anspråk med en biocheck.

Det är vår förhoppning att denna studie ska bidra till en ökad insikt i hur motivation påverkar prestation på olika uppgifter. För ytterligare information kontaktar antingen undertecknad eller huvudansvariga för studien: Torkel Klingberg och Sissela Bergman Nutley.

Deltagande är frivilligt. För att anmäla deltagande, vänligen se nästa sida för svarsblankett.

Daniel Labbé
Solna
den 20 februari 2012

Värt att veta

Dataspelen i studien utvecklas i samarbete med Cogmed Systems AB, Pearson Clinical Assessment Group. Forskningen bedrivs som ett examensarbete för en magister i kognitiv neurovetenskap i ett samarbete mellan Högskolan i Skövde och Karolinska Institutet. Andra forskare kan komma att ta del av insamlad data, men all data anonymiseras i samband med digitaliseringen.
Appendix D: Informed consent

SVARSBLANKETT

Barnets namn:

Vänligen kryssa för ETT av alternativen (JA/NEJ) nedan

JA, jag ger mitt tillstånd till att mitt barn medverkar i studien


NEJ, jag ger inte tillstånd till att mitt barn deltar i studien

Ort, datum

Förälders/Vårdnadshavares namnteckning Namnförtydligande
Appendix E: Motivation questionnaire

Start tid: ___ Slut tid: ___

Frågeformulär

Namn: __________________________

Ålder: ______

Flicka         Pojke
☐          ☐

Född i månad

Januari  Februari  Mars  April  Maj  Juni
☐         ☐          ☐       ☐       ☐       ☐

Juli  Augusti  September  Oktober  November  December
☐         ☐          ☐       ☐       ☐       ☐

Övriga

kommentarer:__________________________________________
Instruktioner

Nu ska du få spela några spel på datorn. Spelen är lite olika, men de har en sak gemensamt: att träna minnet.

Det är ett särskild slags minne som vi vill träna: arbetsminne. Arbetsminnet använder vi när vi försöker hålla information i minnet under kortare tid. Till exempel när man räknar och försöker hålla siffror i huvudet eller när man tittar i en kokbok och sedan försöker komma ihåg vilka ingredienser som behövs när man bakar något.

Före träning

Nu ska jag fråga dig, tror du att det kommer bli roligt att spela de här spelen?

<table>
<thead>
<tr>
<th>Håller inte alls med</th>
<th>Håller helt med</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tror att jag kommer att tycka det är:</strong></td>
<td>1</td>
</tr>
<tr>
<td>Roligt</td>
<td></td>
</tr>
<tr>
<td>Lätt</td>
<td></td>
</tr>
<tr>
<td>Svår</td>
<td></td>
</tr>
</tbody>
</table>
Time Reproduction Task

Nu ska vi göra en uppgift som har med tid att göra.

Visuell datalänk

Efter varje avslutad spelomgång, skriv in hur många minuter du tror att du spelat (Om du skulle gissa hur många minuter du har spelat, inga spel är längre än 15 minuter).

_________minuter
Tyckte du att tiden gick snabbare än vanligt?

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Stämmer inte alls</td>
<td>Stämmer delvis</td>
<td>Stämmer helt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CWM


Exempel:

Om jag lägger dessa två bilder precis framför varandra, så ser de precis likadana ut som i en spegel.
Om jag nu lägger de här bilderna framför varandra så ser man att de svarta inte hamnar på samma plats som det vita, detta betyder att de inte är spegelvända.

Nu kan vi titta tillsammans på dessa bilder och så får du säga vilka bilder som är spegelvända eller inte. [Försöksledaren tar fram kort]

**Är bilderna varandras spegelbild?**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ja</td>
<td>Nej</td>
<td>Nej</td>
<td>Ja</td>
</tr>
<tr>
<td>Nej</td>
<td>Ja</td>
<td>Ja</td>
<td>Nej</td>
</tr>
<tr>
<td>Ja</td>
<td>Nej</td>
<td>Nej</td>
<td>Ja</td>
</tr>
<tr>
<td>Nej</td>
<td>Ja</td>
<td>Ja</td>
<td>Nej</td>
</tr>
</tbody>
</table>

Hur många minuter du tror att du spelat?

__________minuter
Tyckte du att tiden gick snabbare än vanligt?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stämmer inte alls</td>
<td>Stämmer delvis</td>
<td>Stämmer helt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rymdpatrullen [SMP]
Hur många minuter du tror att du spelat?

__________ minuter

Tyckte du att tiden gick snabbare än vanligt?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stämmer inte alls</td>
<td>Stämmer delvis</td>
<td>Stämmer helt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CWM

Kommer du ihåg vad spegelvändning var nu igen?

(Om inte, gå över det igen och demonstrera)

Hur många minuter du tror att du spelat?

__________ minuter

Tyckte du att tiden gick snabbare än vanligt?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stämmer inte alls</td>
<td>Stämmer delvis</td>
<td>Stämmer helt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**n-back**

Nu kommer du att få se lampor som tänds och släcks och det gäller att hålla koll på om de tänds på samma ställe som precis innan. Man ska alltså hålla koll på om den lampa som lyser är samma som den förra lampan som lös. Om det är samma som förra så ska man trycka på mellanslagstangenten och om det inte var samma som den förra så ska man trycka på knapp Z. Hela tiden gäller det att titta på om den som lyser nu är samma som den förra lampan som lös. Så om samma lampa lyser två gånger i rad så ska du trycka på mellanslagstangenten.

Nu är du redo för nästa nivå. Nu ska man istället hålla koll på om lampan som lyser just nu är samma som den förrförra lampan som lös!

Istället för att se om det är samma lampa som lyser två gånger i rad, ska du nu se om det blir samma lampa igen efter att en annan lampa har tänds emellan.
Hur många minuter du tror att du spelat?

__________minuter

Tyckte du att tiden gick snabbare än vanligt?


1 2 3 4 5 6 7
Stämmer inte alls Stämmer delvis Stämmer helt
Efter träning

Nedan följer ett antal påståenden om hur du tyckte att hjärnträningen var.

Vi vill att du sätter ett kryss i den ruta som bäst passar med hur du upplevde den uppgift du hade, där 5= håller helt med, och 1= håller inte alls med.

<table>
<thead>
<tr>
<th>Håller inte alls</th>
<th>Håller helt med</th>
</tr>
</thead>
<tbody>
<tr>
<td>Håller inte alls</td>
<td></td>
</tr>
<tr>
<td>Håller helt med</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Jag tyckte att träningen var:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolig</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lätt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Svår</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tråkig</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enformig</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utmanande</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motiverande</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Tänk på den träning du genomfört idag och svara på påståendena om denna träning. Du ska kryssa i ett av 7 steg för varje påstående.

1 = stämmer inte alls

4 = stämmer delvis

7 = stämmer helt

Ta gärna god tid på dig när du svarar på frågorna.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stämmer inte alls</td>
<td>Stämmer delvis</td>
<td>Stämmer helt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. När jag gjorde träningen, tänkte jag på hur mycket jag tyckte om det jag gjorde.

2. Jag tror att träningen jag gjort kan vara bra för mig.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |


| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

5. Jag tror att det gick bra för mig på träningen, jämfört med andra elever.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
Om 1 betyder tråkigast och 6 betyder roligast, hur skulle du numrerera spelen med siffrorna 1 till 6? Skriv 1 under det roligaste spelet. Skriv 2 under det näst roligaste spelet. Fortsätt sedan med 3 och så vidare.

A________minuter   B________minuter   C________minuter

D________minuter   E________minuter   F________minuter

______________________________

Spelar du andra datorspel?

Ja  [ ]   Nej [ ]

Om du spelar andra datorspel, skriv namnet på ett spel du tycker är roligt att spela: _________________________________

_Tack för ditt bidrag till vetenskapen!_
Appendix F: Sensitivity analysis