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SENSOPROTRAINER®, THE NEW FITNESS DEVICE: EFFECTS OF A SINGLE BOUT OF EXERCISE AND A FOUR WEEK TRAINING PROGRAMME ON MOTOR MEMORY CONSOLIDATION

Master's thesis to obtain the title Master of Science in

Movement and Sport Sciences

Option Health and Research

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Abstract

Introduction: The effects of regular physical exercise on human beings' health and well-being are well-known, but there is also a growing body of empirical evidence supporting the capacity of aerobic exercise in maintaining or enhancing cognition, executive functions, memory and learning (M&L) as well as decreasing the risks of dementia and normal age-related cognitive decline. In 2012, Roig et al. explored the effects of a single bout of exercise on motor memory and discovered that one bout of exercise performed immediately after learning a motor task maximises its long-term retention. A recent review of the literature (Roig et al., 2013) shows that a strategic combination of acute and long-term exercise interventions would increase the different benefits these regimes have on memory formation. In the present study, it was investigated whether a single bout of high-intensity training (HIT) on the SensoProTrainer® (SPT) performed directly after learning a motor task can improve memory consolidation. Additionally, we aimed to determine whether a four week training programme would further promote the expected differences between an intervention group (IG) and a control group (CG).

Methods: A total of 30 untrained (<150 min of physical exercise a week) volunteers (23.2 ± 2.7 years old; 170.6 ± 8.8 cm; 66.5 ± 12.7 kg) were divided into an IG (11 female and 4 male participants) and a CG (11 female and 4 male participants). Participants learned a visuomotor accuracy-tracking task (AT) followed either by a 12 min HIT on the SensoProTrainer® (SPT) and 18 min of rest (IG) or a 30 min resting period (CG). Motor skill retention was assessed 30 minutes (RET1), 24 hours (RET2) and 7 days (RET3) after the learning phase. Participants' fitness level was determined with a graded cardiovascular exercise test on the treadmill after RET2. Following the pre-tests, IG took part in a four week intervention programme on the SPT at a rate of three sessions (ca. 30 min) a week. At the end of these four weeks, all participants were tested for a second time. Both pre and post-tests used identical methods and protocols, with exception of the learning of a new AT.

Results: The analysis of variance (ANOVA) of the graded cardio test showed a significant group*time interaction effect [$F(1, 28)=6.24$; $p=0.017$)]. The improvement of the IG's maximal running speed was highly significant ($p<0.001$), whereas the CG's performance stayed constant. In the pre-test AT learning phase, the ANOVA showed a highly significant time effect ($p<0.001$) but no significant group*time interaction effect [$F(30, 780)=9.76$; $p= 0.99$)]. Both groups learned the task with no difference in performance. The data for RET3 was biased due to a methodological error and was ignored for further analysis. The group*time interaction effect [$F(1, 27)=3.99$; $p= 0.056$)] in the AT performance at RET1 and RET2 was bordering on statistical significance. Indeed, IG's improvement from RET1 to RET2 was significant ($p=0.05$), whilst the CG lacked progress ($p=0.36$). The analysis of the data from the AT learning phase of the post-tests showed that neither group learned the AT. Here, the CG's performance was significantly ($p=0.002$) better than that of IG.

Discussion and Conclusions: Despite the effects not being as substantial as in the study by Roig et al. (2012), the present data partially supports their findings. Indeed, in contrast with CG, IG had a tendency to show improvements from RET1 to RET2 in the pre-test data, which supposes a higher long-term retention of the skill. Performances at the post-test learning phase showed no learning of the motor skill rendering further analysis of potentially enhanced consolidation, due to higher fitness levels, ineffective. There are several potential explanations for the mediocre results and this research equally has fundamental limitations such as the study design and the characteristics of the SPT. A better design with a rethought and improved AT could possibly lead to more positive outcomes.

1. Introduction

Throughout their existence, human beings are constantly confronted with an enormous number of situations to which they have to act and react. These daily experiences are used to reinforce knowledge about the world thus allowing appropriate behaviour in given circumstances. Humans are extremely adaptable and learning creatures and, in the long run, new challenges cause the human body and brain to change. We learn to adapt our behaviour to the environment and, consequently, the skills and knowledge we acquire and remember determine who we are. According to Kandel, Kupfermann and Iversen (2000), “learning is the process by which we acquire knowledge about the world, while memory is the process by which that knowledge is encoded, stored, and later retrieved” (p.1227). To simplify, learning is the acquisition of skill and/or knowledge, and memory is the expression of what has been acquired. Although memory and learning (M&L) are fundamental requirements for human survival, these complex processes cannot simply be measured and have to be inferred from observing and quantifying behaviour (Cahill, McGaugh, & Weinberger, 2001).

M&L research dates back hundreds of years. It initially aimed to find out where and how knowledge is stored in the brain but also focused on the basic principles and processes. Furthermore, many studies concentrated on determining the underlying cellular mechanisms that are involved when information is acquired and retained. To date, the curiosity about M&L has never ceased since it is of common interest for researchers in many areas such as education, rehabilitation and sports to identify how M&L can be enhanced. From a practitioner’s point of view, it is of great significance to better understand the factors that influence skill learning as it would help implementation of conditions promoting higher performances for their students, patients and athletes. Recently, empirical evidence has shown that aerobic exercise not only has many positive influences on physical well-being (Warburton, Nicol, & Bredin, 2006), it also maintains or benefits several aspects of academic performance and cognition (Hillman, Erickson, & Kramer, 2008), as well as memory (Erickson et al., 2011; Roig, Nordbrandt, Geertsen, & Nielsen, 2013) throughout a human’s lifespan.

Based on this knowledge and the recent findings of Roig, Skriver, Lundbye-Jensen, Kiens, & Nielsen (2012), the present study aimed to further explore the impact of performing an intense bout of exercise immediately after acquiring a motor skill, while specifically focusing on the potential effects on the long-term retention of the task. In addition, a long-term cardiovascular intervention was implemented to investigate whether this would support the benefits of the acute exercise on memory consolidation. In contrast to previous studies, the mode of exercise chosen was a newly developed fitness device, the SensoProTrainer® (SPT).

This thesis will firstly introduce previous scientific knowledge of M&L, followed by the context and goals of the study. The methodology used in the study is thoroughly explained and results presented. Finally, discussion and conclusions complete this work.

1.1. Scientific Background

In the following chapters, the history behind the discovery of the different types of memory as well as the underlying principles and processes of memory formation of both implicit and explicit memory will be discussed. Then, a more detailed explanation of how human beings learn motor skills will follow and, finally, the factors that positively and negatively influence memory and learning will also be covered.

1.1.1. Localisation and classification of memory

The interest of localising mental functions in the brain began in the 1790's with the German physician Franz Joseph Gall. He had the intuition that mental functions (he called organs) were localised in separate parts of the brain and their functional strength could be determined by the size of the bulge that could be felt on a person's skull (Simpson, 2005). Although parts of these beliefs were not entirely erroneous and other scientists extended the proposed ideas, this specific doctrine, known as phrenology, was later set aside by further research in the field of neuroscience.

Later in the nineteenth century (1861), the French neurologist Pierre Paul Broca discovered that a lesion in the posterior region of the frontal lobe of the left hemisphere (Broca's area as we know it today) causes expressive aphasia, described by the loss of the capacity to produce language (Kandel, 2000a). In turn, in 1876, the German scientist Carl Wernicke discovered receptive aphasia, characterised by the incapacity to understand written and spoken language. In contrast to expressive aphasia, receptive aphasia is caused by injuries to the (now called) Wernicke area, which is situated in the posterior part of the temporal lobe (Kandel, 2000a). As a result, it was concluded that production and comprehension of language are managed by two different cortical areas responsible for the motor and sensory aspects of language. In other words, the different components of a behaviour, in this case language, are treated in different parts of the cerebral cortex (Kandel, 2000a). These findings took knowledge to another level and allowed Wernicke to argue that "only the most basic mental functions are localised to single areas in the cortex. More complex cognitive functions result from interconnections between several functional sites" (Kandel, 2000a, p. 11). This brings to light that other mental skills, such as M&L, must also be governed by specific neural circuits and be located in discrete areas of the brain (Kandel et al., 2000). Thus, further understanding of these two core processes of human behaviour became a central aspect in neurophysiologic research.

Following Broca and Wernicke's footsteps, the American psychologist and behaviourist Karl Joseph Lashley, largely contributed to the study of M&L by attempting to locate the area of the brain in which memory was stored. Thanks to his interest in rats and their capacity to run through a maze after having undergone brain lesions in various sites, Lashley concluded that M&L had no specific cerebral locus (Kandel, 2000a) nor critical pathway, but were spread across the brain and were integrated with intellectual and perceptual functions (Eichenbaum, 2013). Indeed, as none of the surgeries abolished the rats' previously learned habits, it was thought that memories must be stored in several locations.

During the second part of the twentieth century, the study of a patient who had undergone the bilateral extraction of parts of his temporal lobes, such as the hippocampal formation (i.e., the hippocampus, the subiculum and the dentate gyrus), the amygdala and portions of the multimodal association area, revealed “fundamental principles about how memory functions are organised in the brain” (Squire, 2009, p. 6) and greatly contrasted previous opinions. Indeed, according to Kandel and colleagues (2000), Henry Gustav Molaison (H.M.) suffered from seizures in his temporal lobes which pushed his neurosurgeon William Scoville to remove the above mentioned parts of his brain. Following the experimental surgery, H.M.’s epilepsy was better controlled. However, he newly suffered from severe memory impairment called anterograde amnesia. His IQ stayed the same, his short-term memory as well as his working memory were undamaged and he could perfectly remember experiences from his past (with exception of a few years preceding the surgical intervention). In contrast, he was unable to recall daily events and novel facts (faces, names, objects, etc.) because he was incapable to transfer the newly acquired information from short to long-term memory (Kandel et al., 2000). In others words, his perceptual and cognitive capacities were intact but his long-term memory was impaired (Eichenbaum, 2013). The study of H.M. revolutionised the beliefs by establishing that memory is a discrete cerebral function and that the medial parts of the temporal lobes are crucial for its appropriate function (Squire, 2009).

Although H.M suffered from profound memory impairment, he was still able to “learn certain types of tasks and retain this learning for as long as normal subjects” (Kandel et al., 2000, p. 1229). Indeed, Brenda Milner, a British neuropsychology student made a revolutionary discovery when she tested patient H.M’s abilities to learn a visuomotor skill (Fig. 1A). He was able to acquire the ability, he became proficient with practice (Fig.1B) and he achieved excellent performances at the retention tests, but after each practice session he had no recollection of doing the task before (Squire, 2009). Every time he came back to practice, it was a new experience for him. Squire (2009) argued that “this demonstration provided the first hint that there was more than one type of memory in the brain and suggested that some kinds of memory (motor skills) must lie outside the province of the medial temporal lobe" (p.8). This was later confirmed with the discovery of additional exceptions to otherwise severe memory deficits seen in patients with lesions to the medial temporal lobe. Likewise, these patients had intact perceptual learning, normal priming (i.e., "improved facility for detecting or processing a perceptual object based on recent experience" (Squire, 1992, p. 234)) and unaffected cognitive skills (Eichenbaum, 2013).

These findings suggest that there are two main distinctive forms of long-term memory and knowledge: declarative or explicit and non-declarative or implicit. The former refers to the conscious recollections of facts and events about people, places and things (often described as "knowing what"), whereas the latter concerns skill-based knowledge (also known as "knowing how"), that is acquired with time, recalled unconsciously and expressed as a performance as opposed to words (Cohen & Squire, 1980). Cognitive, motor and perceptual skills as well as learning rules and procedures are typical examples of implicit memories (Kandel et al., 2000).

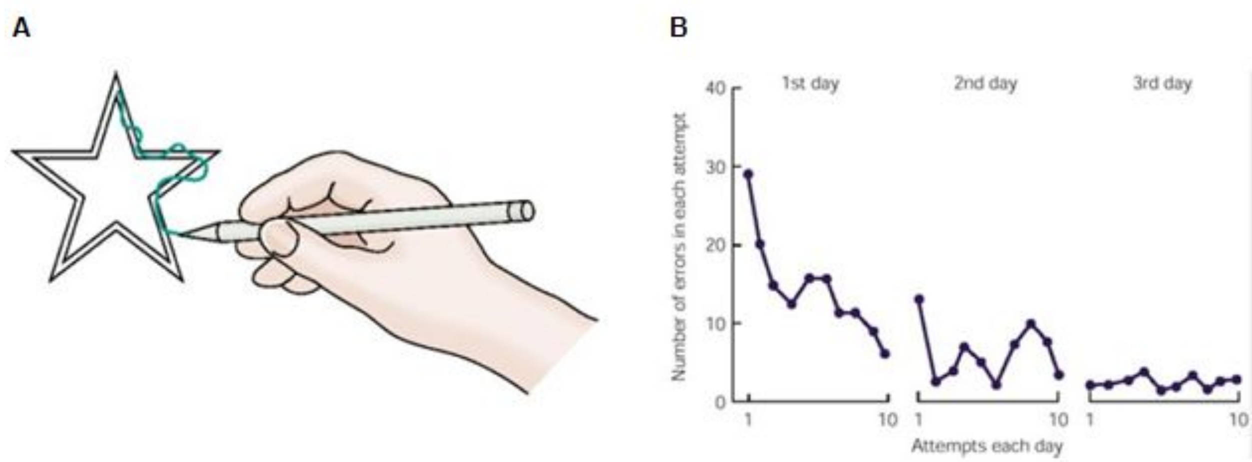


Fig. 1: Example of a motor skill learned by patient H.M. Reprinted from *Principles of Neural Science* (p.1230), by E.R. Kandel, 2000, New York: McGraw-Hill. Copyright (2000) by the McGraw-Hill Companies. **A.** Patient H.M. was capable of learning to draw between two outlines of a star at a normal rate while looking at his hand in a mirror. **B.** He initially made mistakes but with training his performance progressed and on the third day of practice it was error-free and identical to the performance of normal subjects.

Finally, studies on both amnesic and healthy subjects demonstrated that damage to specific parts of the brain cause impairments in discrete forms of long-term memory. The fact that amnesic patients fail tasks of recollection and recognition (dependent on declarative memory) but retain their ability to learn new skills, implies that declarative and non-declarative memories do not only have different characteristics but also depend on separate brain systems (Squire, 1992). Additionally, research on animals (mainly rats and monkeys) with lesions in restricted areas of the brain enabled scientists to draw precise deductions on the importance of the damaged regions in human memory (Kandel et al., 2000). Moreover, this research showed that “the hippocampus and the surrounding cortical areas interconnected with the hippocampus support distinct roles in memory formation” (Eichenbaum, 2013). Taking into account all these findings, it was concluded that declarative memory refers to a “biologically meaningful category of memory” (Squire, 1992, p. 233) that depends on specific brain structures and connections in the medial temporal lobe, when in fact non-declarative memory includes a collection of M&L abilities that depends on multiple brain systems, such as motor cortical areas and various subcortical areas (including the striatum, cerebellum, neocortex and amygdala) (Squire, 1992). The human’s “multiple memory systems” (Squire, 2009, p. 7) is concisely illustrated in a figure that shows the classification of the different forms of memory and as well as brain areas they respectively depend on (Fig. 2).

In the present study conducted as part of this master’s thesis, the participants were asked to learn a visuomotor accuracy-tacking task (AT). Acquiring this task involved non-declarative memory. The following chapter will therefore briefly discuss how different forms of implicit memory are acquired and what brain regions are implicated in the formation of these types of memories.

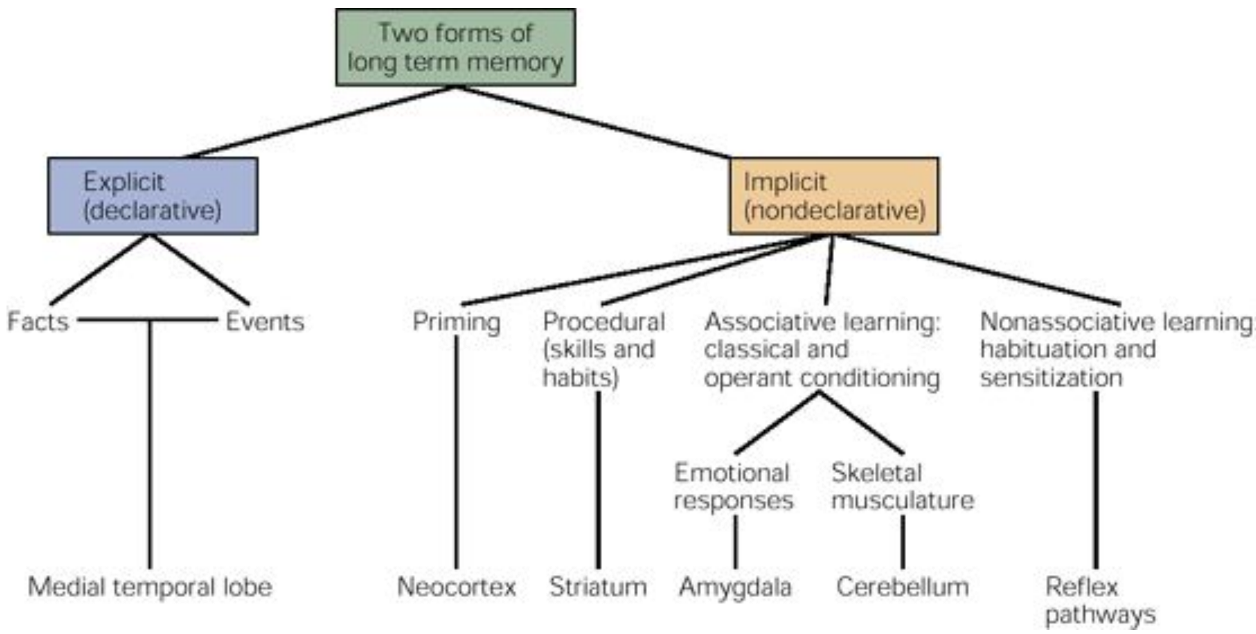


Fig. 2: Different forms of memory and learning. Reprinted from *Principles of Neural Science* (p.1248-1231), by E.R. Kandel, 2000, New York: McGraw-Hill. Copyright (2000) by the McGraw-Hill Companies.

1.1.2. Non-declarative memory and learning

As previously discussed and illustrated in figure 2,

> non-declarative memory includes information that is acquired through skill learning (motor, perceptual and cognitive), habit formation, simple classical conditioning including some kinds of emotional learning, the phenomenon of priming, and other knowledge that is expressed through performance rather than recollection. (Squire, 1992, p. 233).

All these major forms of learning involve different brain areas and systems such as the amygdala, the striatum, the cerebellum, the neocortex and other reflexive pathways (Kandel et al., 2000). In this chapter, some of the founding principles of implicit learning will be addressed so as to have a better understanding of what happens when something is learned.

According to Kandel et al. (2000), two main subclasses of non-declarative learning have been established: (1) non-associative and (2) associative learning. This differentiation is made on the basis that behaviour is altered in response to a single event in non-associative learning or according to the relationship between two stimuli or that of a stimulus and a specific behaviour in associative learning. These procedures were initially studied in vertebrates on various occasions by several scientists such as Ivan Pavlov, Charles Sherrington, Alden Spencer and Richard Thompson, but the species' complexity (10^{12} neurons in the nervous system of many higher order mammals) set many barriers for the analysis of the underlying mechanisms. Therefore, due to its simple nervous system (i.e., mere 20'000 large and easily identifiable neurons), the Aplysia californica (Fig. 3A) was the ideal species to investigate neural changes and became the model system for further neurobiological analysis of M&L (Kandel, 2000b). The mechanisms discovered through experiments conducted on this invertebrate are the basis of many types of learning. Nobel Prize winner Eric Kandel initially focused his research on the responsiveness of this marine sea slug to an aversive stimulus (Fig.3B), which closely resembles the leg withdrawal reflex previously studied in humans.

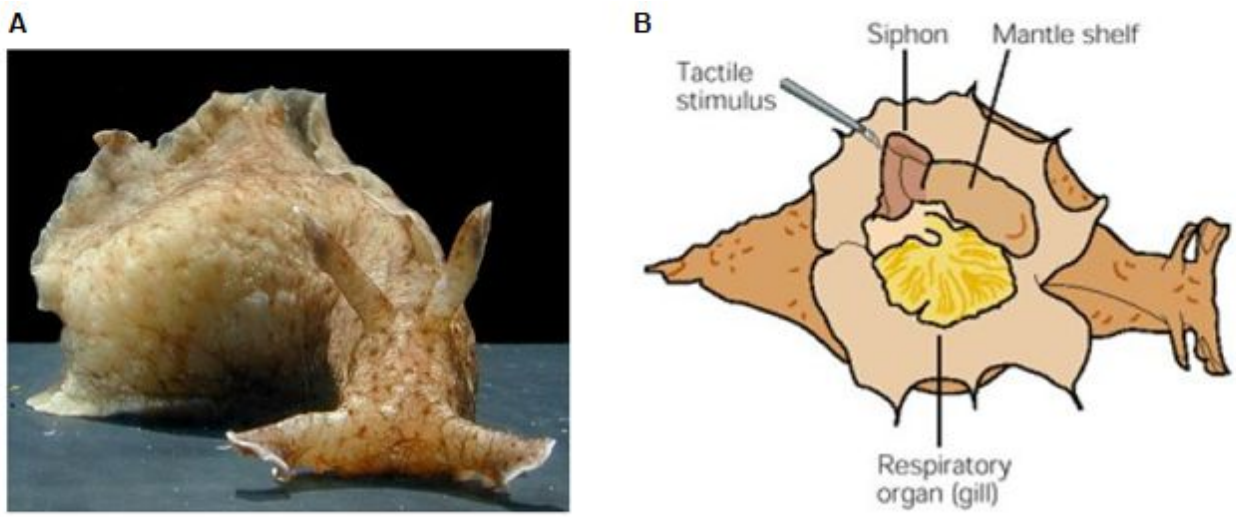


Fig. 3: A. Photo of the Aplysia californica. Reprinted from *Biologist With A Twist: Dr. Carin Bonder*, by C. Bonder. 2013. Copyright (2012) by Dr. Carin Bonder. Retrieved January 22, 2014, from http://carinbondar.com/2010/10/the-nudibranch-smoothie-two-out-of-three-hermit-crabs-prefer-it/
B. Experimental study model: the marine slug Aplysia californica. Reprinted from *Principles of Neural Science* (p.1248), by E.R. Kandel, 2000, New York: McGraw-Hill. Copyright (2000) by the McGraw-Hill Companies.
The dorsal view shows the major organs for the sea slug (i.e., the siphon, the gill and the mantle shelf).

On the basis of the findings of Eric Kandel, a brief description of habituation and sensitization, two forms of non-associative learning, as well as the cellular and biological mechanisms involved in the formation of short and long-term memory will be discussed in this chapter.

a. Habituation

Habituation, considered to be the simplest form of non-associative implicit learning, is defined as “a decrease in response to a benign stimulus when that stimulus is presented repeatedly” (Kandel et al., 2000, p. 1240). Both short-term habituation (STH) and long-term habituation (LTH) were investigated in the gill-withdrawal reflex of the Aplysia. It was shown that a “mild tactile stimulus delivered to the siphon elicits reflex withdrawal of both the siphon and the gill. With repeated stimulation these reflexes habituate” (Kandel, 2000b, p. 1249). In this homosynaptic process, the sensory neurons (SN) that innervate the siphon’s skin form synapses with motor neurons (MN) within the abdominal ganglion, which, in turn, innervate the gill through the intermediary of excitatory and inhibitory interneurons (IN). Repeatedly stimulating the siphon decreases the transmission through all synapses involved in the circuit, meaning that the stimulus is finally being ignored (Fig. 4) (Kandel, 2000b). The diminished efficacy of the sensorimotor synapses in STH is due to a decreased number of SN presynaptic transmitter vesicles released per action potential (Castellucci & Kandel, 1974). However, all receptors (i.e., NMDA and non-NMDA) in the motor cells remain fully sensitive to glutamate (i.e., the neurotransmitter used by the SN) (Kandel, 2000b).

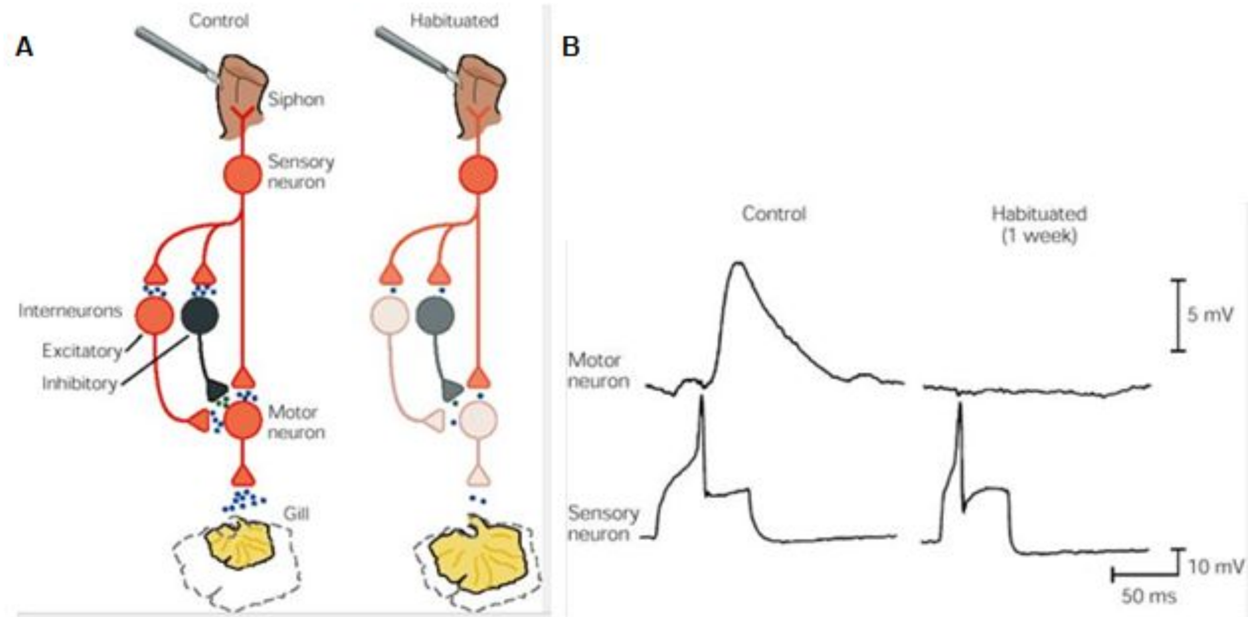


Fig. 4: Habituation of the gill-withdrawal reflex in Aplysia californica. Reprinted from *Principles of Neural Science* (p.1248-1249), by E.R. Kandel, 2000, New York: McGraw-Hill. Copyright (2000) by the McGraw-Hill Companies.
A. Glutaminergic sensory cells form synapses with both motor neurons and interneurons that form synapses with motor neurons. In the habituated gill-withdrawal reflex, the repeated stimulation to the siphon causes the synaptic transmission at all connections to decrease, whereas the control Aplysia's gill-withdrawal reflex remains normal. **B.** Illustration of the difference between a habituated and a control animal. The synaptic potentials in the motor neuron are inexistent after 1 week of long-term habituation.

Kandel (2000b) concludes that learning leads to initial changes in synaptic strength and that these plastic changes mediate short-term memory for habituation. Consequently, the duration of retention of the information in short-term memory highly depends on the duration of the plastic change. As little as 10 tactile stimuli can cause STH with alterations in synapse transmission that last a maximum of 30 min. In contrast, when it comes to LTH, the chosen training methods highly impact the retention in long-term memory. A prolonged change in synaptic strength that can last as long as three weeks was achieved through spaced habituation training (i.e., five sessions of 10 tactile stimuli interspersed with rest) (Carew, Pinsker, & Kandel, 1972; Kandel, 2000b). In contrast, massed training (i.e., no rest allocated between habituation training sessions) resulted in strong short-term memory but long-term memory was jeopardised (Kandel, 2000b). From a practical point of view, Kandel (2000b) concludes that spaced training is always a better training method for the long-term retention of learned skills than massed training.

b. Sensitisation

Sensitisation is defined as the “amplification of defensive behavioural responses in response to aversive or noxious stimuli that cause or can lead to pain” (Rahn, Guzman-Karlsson, & David Sweatt, 2013, p. 133). After a harmful stimulus, all defensive reflexes are increased even if the next applied stimulus is harmless. Consequently, the effects of habituation can be reversed; this process is called dishabituation (Kandel, 2000b).

The mechanism of sensitisation of the gill is a heterosynaptic facilitation of presynaptic transmission. The enhancement of synaptic strength at several connections in the neural circuit of the gill-withdrawal reflex is induced by facilitating IN activated by the noxious stimulation of the tail (Kandel, 2000b). In other words, tail stimulation activates its SN which, in turn, excite the modulatory IN that form axo-axonic synapses with the siphon’s SN presynaptic terminals (Fig. 5). At these sites, the presynaptic IN release elevated quantities of serotonin (5-HT) which induce augmented levels of neurotransmitter discharge from the siphon’s SN. Finally, this causes an enhanced and prolonged gill withdrawal (Kandel, 2000b).

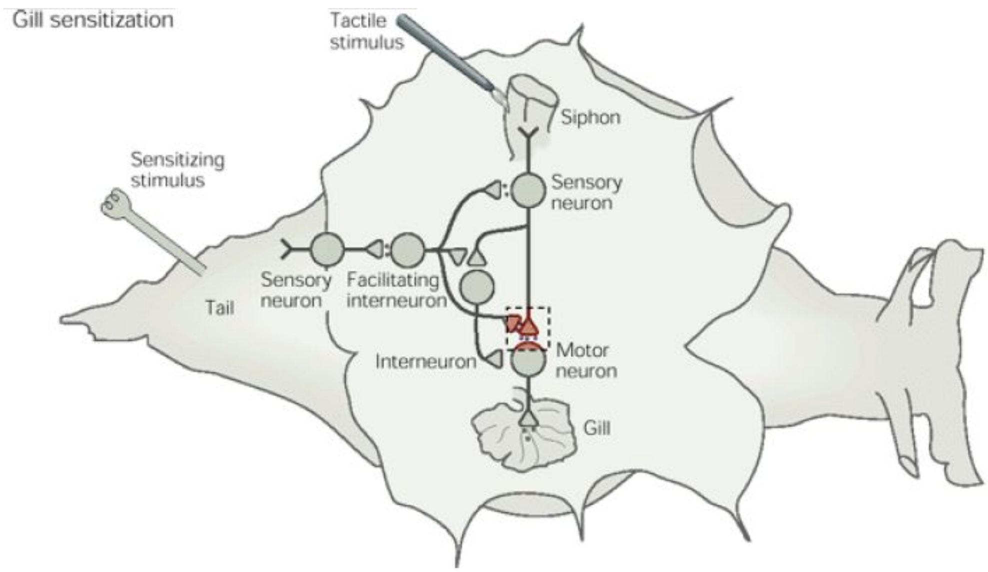


Fig. 5: Sensitisation of the gill-withdrawal reflex in Aplysia californica. Reprinted from *Principles of Neural Science* (p.1251), by E.R. Kandel, 2000, New York: McGraw-Hill. Copyright (2000) by the McGraw-Hill Companies.
Short-term presynaptic facilitation of the gill-withdrawal reflex is initiated by a facilitating interneuron releasing serotonin. This induces various biochemical pathways that cause enhanced transmitter release from sensory neurons and ultimately prolonged gill withdrawal.

Both short and long-term facilitation can be elicited according to the degree of stimulation. Actually, a single shock to the tail suffices to provoke short-term facilitation (STF) causing a reflex lasting minutes (i.e., < 1 h). This leads to presynaptic modifications of existing proteins only (Bailey, Bartsch, & Kandel, 1996). In contrast, multiple trains of shocks separated in time induce long-term facilitation (LTF) which strengthen the synaptic connections and prolong the gill withdrawal to up to several weeks (Pinsker, Hening, Carew, & Kandel, 1973). Moreover, LTF requires coordinated pre and postsynaptic modifications which involve protein synthesis, changes in gene expression and the growth of new synapses (Bailey et al., 1996; Jin et al., 2012). The molecular mechanisms of STF and LTF involved in the creation of long-term memories will be discussed in the following chapter. Behaviourally, STF and LTF induced gill-withdrawal reflex are referred to as short-term sensitisation (STS) and long-term sensitisation (LTS) respectively (Rahn et al., 2013).

c. Cellular mechanisms of short and long-term memory

According to Kandel (2000b), the relation between STS and LTS as well as STH and LTH are perfect illustrations of consolidation of memory, where a short-term experience is transformed into a long-term state through repetition. Short and long-term memories are closely linked through their identical basic mechanisms. However, the profound difference between these two types of memory lies in the duration and fragility of the retained information. Furthermore, evidence from epilepsy and head injuries show that only long-term memory is affected (Kandel, 2000b). The progression from a state of labile short-term memory to a stable long-term memory involves additional gene expression, protein synthesis and growth of new synaptic connections (Kandel, 2000b). This crucial process in implicit memory formation is called consolidation. Various factors such as attention, mood, exercise and social context can facilitate or hinder the transfer of information from short to long-term memory by respectively lowering or elevating the threshold for consolidation (Kandel, 2000b).

STF and LTF are considered the cellular homolog of short and long-term memory. Thus, the molecular mechanisms involved in STF and LTF are used as an example to illustrate how long-term memories are consolidated (Fig. 6). The molecular processes for STF and LTF are initiated by the release of 5-HT from a presynaptic facilitating IN. As put forward by Kandel (2000b):

> Serotonin acts on a postsynaptic receptor to activate the enzyme adenylyl cyclase, which converts ATP to the second messenger cAMP. In turn, cAMP activates the cAMP-dependent protein kinase A, which phosphorylates and covalently modifies a number of target proteins, leading to enhanced transmitter availability and release. The duration of these modifications is a measure of the short-term memory. (p.1254)

STF leads to modifications of the existing proteins only. In contrast, as previously mentioned, the consolidation of long-term implicit memories involves various functional and structural changes. Again, according to Kandel (2000b), LTF

> is initiated by protein kinase A (PKA), which recruits the mitogen-activated kinase (MAPK) and together they translocate to the nucleus (long-term pathway), where PKA phosphorylates the cAMP response element binding (CREB) protein. The transcriptional activators bind to cAMP response elements (CRE) located in the upstream region of two types of cAMP inducible genes. To activate CREB-1, PKA needs also to remove the repressive action of CREB-2, which is capable of inhibiting the activation capability of CREB-1. PKA is thought to mediate the derepression of CREB-2 by means of another protein, MAPK. One gene activated by CREB encodes a ubiquitin hydrolase, a component of aspecific ubiquitin protease that leads to the regulated proteolysis of the regulatory subunit of PKA. This cleavage of the (inhibitory) regulatory subunit results in persistent activity of PKA, leading to persistent phosphorylation of the substrate proteins of PKA, including both CREB-1 and the protein involved in the short-term process. The second gene activated by CREB encodes another transcription factor C/EBP. This binds to the DNA response element CAAT, which activates genes that encode proteins important for the growth of new synaptic connections. (p. 1254)

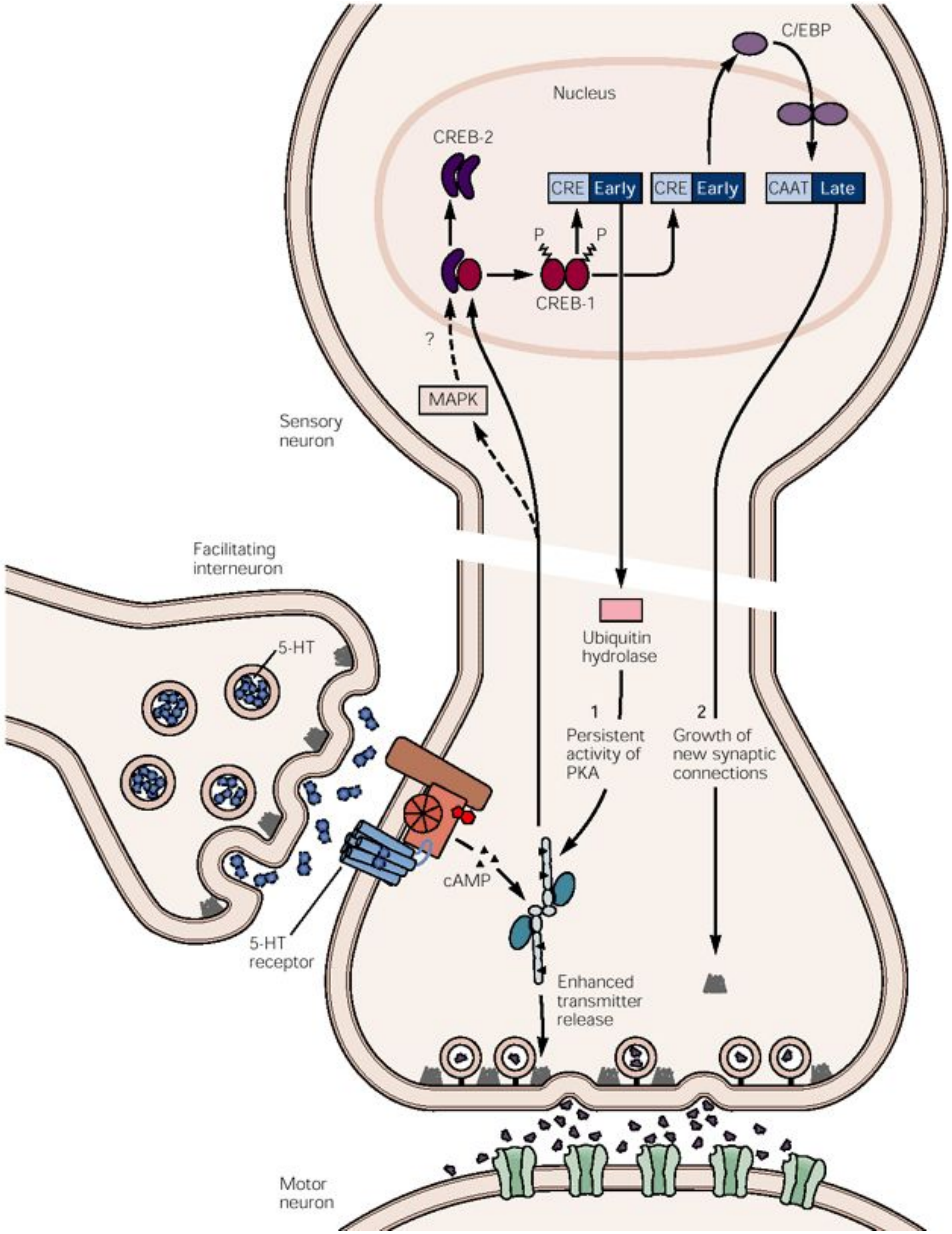


Fig. 6: Molecular mechanisms involved in the long-term sensitisation of the gill-withdrawal reflex in the Aplysia californica. Reprinted from *Principles of Neural Science* (p.1255), by E.R. Kandel, 2000, New York: McGraw-Hill. Copyright (2000) by the McGraw-Hill Companies.

Kandel (2000b) summarises that LTS leads to two major changes in the SN of the gill-withdrawal reflex pathway: (1) Persistent activity of PKA without further activation through training; (2) A cascade of gene activation leading to structural changes in the form of the growth of new synaptic connections. These two changes result in a self-maintained state of long-term memory with an increase in synapses (Fig. 7). In contrast, LTH induces a prolonged inactivation of synaptic connections and therefore results in a loss of synapses (Fig. 7).

As previously mentioned, Kandel used the Aplysia californica for all his experiments because the simplicity of its nervous system rendered the analysis of neural changes that occur during M&L much easier. Although, the central nervous system of human beings and other vertebrates is much more complex, it functions in the same way and it is therefore assumed that all the plastic changes discovered in this basic animal model can be transferred without any limitations to more advanced species.

Fig. 7: Structural changes in long-term habituation (i.e., loss of synpases) and long-term sensitisation (i.e., increase in number of synapses). Reprinted from *Principles of Neural Science* (p.1256), by E.R. Kandel, 2000, New York: McGraw-Hill. Copyright (2000) by the McGraw-Hill Companies.

Non-declarative learning equally comprises the learning of skills and habits (i.e., procedural learning). Due to the importance of fully understanding the notion of motor skill learning for the study conducted for the present work, an entire chapter will be dedicated to how motor skills are learned after discussing the cellular mechanisms involved in the formation of declarative memories.

1.1.3. Declarative memory and learning

Declarative memory "provides the basis for conscious recollections of facts and events" (Squire, 1992, p. 232) and information is stored within the temporal lobe system (Kandel et al., 2000). Additionally, the hippocampus serves as a mediator for long-term storage of memories and once the information is permanently saved it is no longer required for recall (Kandel et al., 2000). In other words, the hippocampus is crucial for long-term memory formation but not for storage or retrieval.

In comparison to implicit memories discussed in the previous chapter (see 1.1.2 Non-declarative memory and learning), the formation of explicit memories in mammals involves a different mechanism. In 1973, Bliss and Lømo discovered that the neurons of the hippocampus have prolonged plastic capabilities and a brief intense stimulation of one of its three major neural pathways (i.e., the perforant fiber pathway, the mossy fiber pathway and the Schaffer collateral pathway) results in an elevated synaptic efficacy that can last up to several days (Bailey et al., 1996). Here, facilitation is called long-term potentiation (LTP) which has two phases, namely early LTP and late LTP. According to Kandel (Kandel, 2000b), the former is induced by a single tetanus, lasts 1-3 hours and corresponds to a functional change that does not need protein synthesis, whereas the latter requires four or more trains of stimuli to provoke changes lasting a minimum of 24 hours and is a structural change that depends on new protein and RNA synthesis. The molecular mechanisms for the transient early phase of LTP in the different pathways are not entirely identical but it seems like the consolidated late phase of LTP is similar. Consequently, a general model for the two different phases of LTP (Fig. 8) has been created. According to Kandel (2000b),

> A single train of action potentials leads to early LTP by activating NMDA receptors, Ca2+ influx into the postsynaptic cell, and a set of second messengers. With repeated trains the Ca2+ influx also recruits an adenylyl cyclase, which activates the cAMP-dependent protein kinase (cAMP kinase) leading to its translocation to the nucleus, where it phosphorylates the CREB protein. CREB in turn activates targets that are thought to lead to structural changes. (p.1265)

One of the main targets that supposedly leads to the structural changes required for long-term memory formation is brain-derived neurotrophic factor (BDNF). The action and effects of this neurotrophin will be thoroughly discussed in a later chapter.

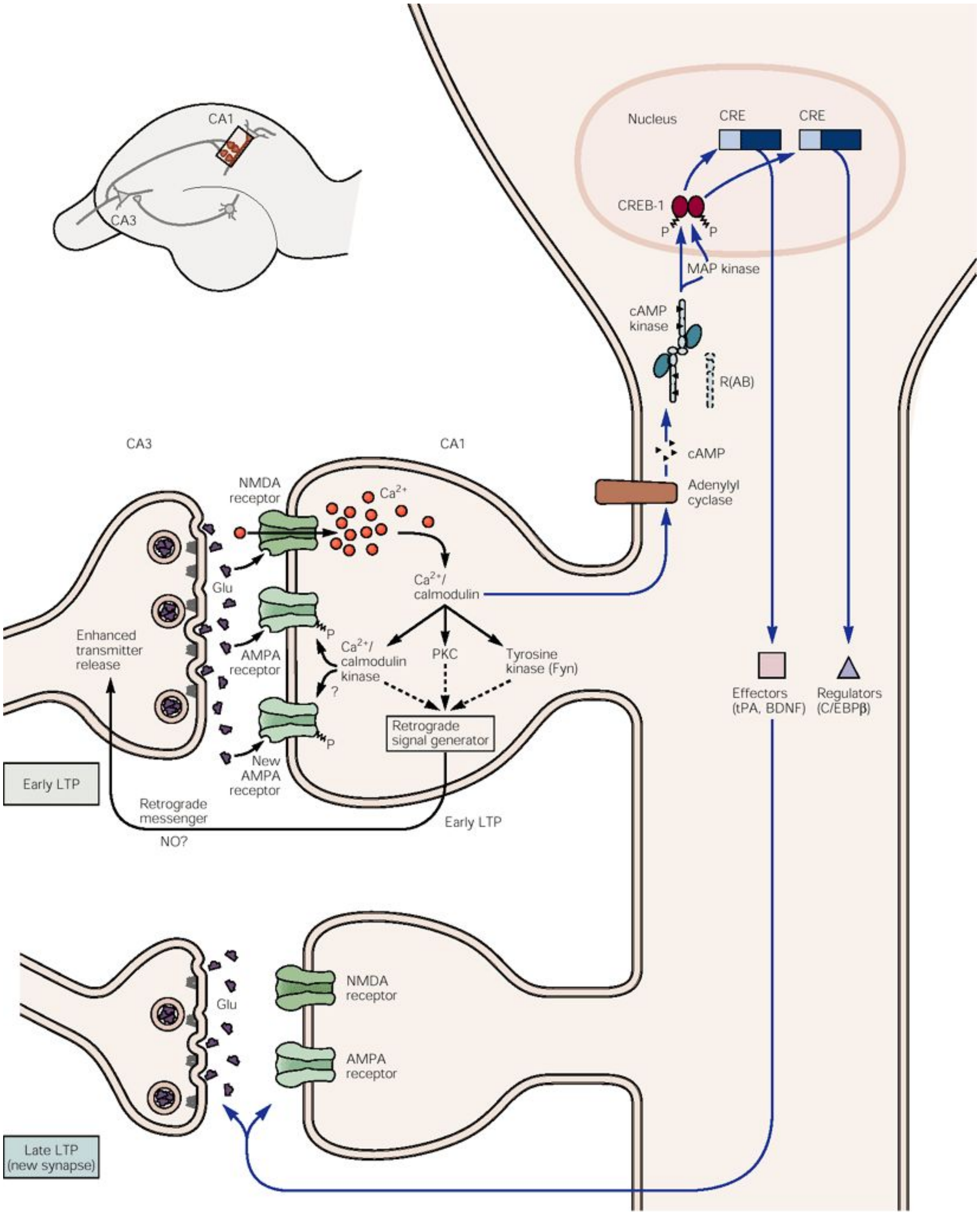


Fig. 8: A model of both early and late phases of LTP. Reprinted from *Principles of Neural Science* (p.1264), by E.R. Kandel, 2000, New York: McGraw-Hill. Copyright (2000) by the McGraw-Hill Companies.

To summarise, like implicit memory, the consolidation of explicit memory involves structural changes in the form of the synthesis of new proteins. Moreover, the formation of both types of memory involves similar processes such as cAMP-mediated transcription, which is a common mechanism between presynaptic facilitation and late LTP (Bailey et al., 1996).

Now that the cellular mechanisms involved in the formation of long-term memories have been discussed, the following chapter will address motor skill learning and performance. Firstly, immediate performance and learning will be defined and differentiated. Secondly, the processes involved in motor memory formation will be briefly described.

1.1.4. Motor skill learning

Interaction with the world is only possible through acquisition and long-term retention of various skills, but primarily motor skills. According to Luft & Bruitago (2005),

> the term motor learning is used for various paradigms involving movement, such as conditioning that requires the association of a stimulus with a motor reflex response, learning the control of reflex gains, learning to improve a reaction time, learning a finger tapping sequence, serial reaction time task or adjusting movements to external perturbations. (p. 205).

As previously mentioned, motor skills are classified as non-declarative memories that develop gradually with time through repetitive training (i.e. practice). In these cases, practice improves motor performance relatively rapidly but the basis of the improvement cannot be verbally described (Reber, 2013). Once mastered, skills are retained for a long period of time and the behavioural change is noticeable as improvements in speed and accuracy of performance (Dayan & Cohen, 2011). However, it is important to distinguish immediate motor performance which is observed during or instantly after practice and motor learning which develops with practice sessions and corresponds to the behaviour sustained in the long-term (Kantak & Winstein, 2012).

According to Kantak and Winstein (2012), many studies have established differences between transient performance (during or immediately after practice) and long-term performance (delayed in time after practice). The reasoning behind this statement is based on the fact that various factors such as feedback, motivation, attention, arousal and the time of day, can influence performance during the initial practice phase (Cahill et al., 2001). Consequently, the performance during or immediately after acquisition can be distorted and might not appropriately reflect the relatively permanent effects of practice (i.e., learning). Thus, in order to infer learning, the performance is measured with a retention test after a certain time interval following practice (usually >24 h) allowing newly encoded memories to consolidate. This test assesses the retention of the same exact skill in identical conditions and gives an indication of the “relative permanence of level of performance achieved in acquisition” (Kantak & Winstein, 2012, p. 221). Results of this retention test reflect how well the motor memory is maintained with time but do not give any information about the mechanisms involved in motor memory formation. In sum, delayed retention is considered to be a better indicator of learning than immediate performance.

Practice of motor skills triggers multiple processes in the central nervous system as well as alterations in functional networks of the brain (Lundbye-Jensen, Petersen, Rothwell, & Nielsen, 2011). These changes within the neural circuits “constitute learning and result in motor memory formation” (Kantak & Winstein, 2012, p. 222). Both declarative and non-declarative memories involve three distinct but complementary processes: (1) encoding; (2) consolidation; (3) retrieval. Encoding is thought to occur during the acquisition phase when the learner practices the motor skill (Kantak & Winstein, 2012) and is defined as a form of “use-dependent plasticity” (Butefisch, Khurana, Kopylev, & Cohen, 2004, p. 2110) . During this phase, information is addressed and processed by making meaningful associations between the different components of the task (i.e., the goal, the movement and the outcome) (Kandel et al., 2000; Kantak & Winstein, 2012). Consequently, several cognitive processes are used to identify the stimulus (i.e., the task), select a response, execute the movement and finally evaluate the outcome in order to make any necessary alterations to better future performances (Kantak &

Winstein, 2012). When practice stops and the encoding phase thus ends, the brain does not stop processing information relative to the newly learned skill; memory consolidation takes over. This offline phase refers to the enhancement of the skill (i.e., performance improvement between practice sessions also named offline learning) and/or the stabilisation of memories (i.e., increased resistance to interference by another task) (Robertson, Pascual-Leone, & Miall, 2004). Indeed, memory consolidation is a slow time-dependent process (McGaugh, 2000) with a time course that appears to be divided into two phases. During the first 6 hours following practice the memory trace is stabilised and the improvement of performance, which is often dependent on sleep and time, takes place in this period (Luft & Buitrago, 2005). Consequently, if a new task B is learned too early (i.e., <4-6 h after the end of the practice) after learning a task A, interference diminishes the retention of the initially learned motor skill A (Luft & Buitrago, 2005). It is therefore crucial to respect consolidation time as this phase is central in motor learning. Finally, retrieval of the encoded, consolidated and stored information is essential for its use and is the only means of assessment of learning and memory (Kantak & Winstein, 2012).

Now that we have a better understanding of the processes and underlying mechanisms of M&L as well as some better knowledge on specific implicit memories such as motor memory, the following chapter will address factors that positively (i.e., exercise) and negatively (i.e., interference) influence M&L.

1.1.5. Factors that influence memory and learning

a. Factors that facilitate memory and learning: effects of exercise

Our modern society has led humankind to alter its behaviour towards physical activity (PA), defined by “any bodily movement produced by the contraction of skeletal muscles that results in a substantial increase in caloric requirements over resting energy expenditure” (ACSM, 2013, p. 2), and towards exercise defined by “a type of physical activity consisting of planned, structured, and repetitive bodily movement done to improve and/or maintain one or more components of physical fitness” (ACSM, 2013, p.

2). In contrast with our predecessors for whom PA was a synonym of survival, industrialised men and women of this day and age no longer have the same perspective. Indeed, mainly in industrialised countries, food no longer has to be hunted for, manual labour has been replaced by machines, pre-cooked meals are often chosen for their convenience and many hours of the day are spent sitting down (e.g., at work, in the car, in public transportation), etc. In sum, the modern man has opted for a sedentary lifestyle. Ironically, mankind's current behaviour is in contradiction with the increasing amount of literature supporting the numerous long-term benefits of regular PA and exercise. This research emphasises the importance of an active lifestyle in the prevention, management and rehabilitation of physical illnesses such as Type II diabetes, obesity, osteoporosis, breast cancer and metabolic syndrome (Warburton et al., 2006). Additionally, many studies have concluded that inactive adults and children are more likely to suffer from depression and anxiety than their active counterparts (Warburton et al., 2006). Finally, the Latin sentence "mens sana in corpora sano" (translated as " a healthy mind in a healthy body") has received heightened attention as studies on both animals (Kobilo et al., 2011) and humans (Hillman et al., 2008) have shown that the beneficial effects of aerobic exercise or physical fitness extend to brain health and various cognitive functions (Voss, Nagamatsu, Liu-Ambrose, & Kramer, 2011).

Indeed, regular physical exercise has the capacity to improve executive functions as well as L&M, counteract age-related mental decline and facilitate functional recovery from brain injury, disease (i.e. Alzheimer's and Parkinson's) and depression (Vaynman & Gomez-Pinilla, 2006). Furthermore, the beneficial relationship between PA and cognition is present in both humans and animals. Although many conclusions concerning the effects of exercise on cognitive processes can be drawn from human studies with the use of neuropsychological tests (i.e., reference paper-crayon and computer tests) and neuroimaging techniques (i.e., event-related potential as well as structural and functional MRI), animal studies permit further exploration of this relationship (Hillman et al., 2008). Hillman et al. (2008) supports the use of non-human studies for the following reasons: (1) invasive methods to examine cellular and molecular mechanisms can be used; (2)

other influences such as diet and social contact are simply excluded; (3) the control of precise training programmes is rendered much easier. Consequently, findings from animal research deepen the empirical evidence on the modifications that occur in human brain structure and function with exercise. Thus, the focus of this chapter is to discuss the valuable effects of exercise on M&L by exposing the underlying mechanisms supporting the influence of regular physical exercise on the brain.

Many animal studies involving environment enrichment (EE) have shed light on the potential mechanisms impacted by an active behaviour. EE consists of an “increased opportunity for learning, socializing and physical activity” (Kobilo et al., 2011, p. 605). Animals exposed to EE are given the possibility to be physically active on running wheels or tunnels, are housed in larger groups allowing enhanced social interaction and are confronted to many complex objects or toys that promote the learning of new skills (Bekinschtein, Oomen, Saksida, & Bussey, 2011). However, it was found that aerobic activity is the critical factor of EE for enhancement of brain function and not EE as a whole (Kobilo et al., 2011). From a general point of view, these animal models (mainly rodents) have helped determine the potential pathways leading to “improvement in both structural integrity of the brain (i.e., growth of new neurons and blood vessels) and increased production of neurochemicals that promote growth, differentiation, survival, and repair of brain cells” (Voss et al., 2011, p. 1508).

Firstly, neurogenesis (i.e., the generation of new neurons) in the dentate gyrus of the hippocampus, an important brain area for M&L, is one of the most commonly observed effects of aerobic training (Hillman et al., 2008). The cell proliferation and enhanced survival induced by exercise is thought to facilitate M&L as well as protect against the decline of neurogenesis with normal ageing (Voss et al., 2011).

Secondly, angiogenesis (i.e., growth of new blood vessels) with its conjugated increase in cerebral blood volume (Pereira et al., 2007) was also a main finding. The augmented need for nutrients caused by neurogenesis induces “new blood vessel growth in the cortex, cerebellum, striatum and hippocampus” (Hillman et al., 2008, p. 62). This more expanded growth contrasts with neurogenesis which only occurs in the hippocampus.

However, like neurogenesis, angiogenesis has equally been linked to improved M&L (Voss et al., 2011).

Thirdly, several circulating neurochemicals that are known to work in conjunction (van Praag, 2008) in order to mediate the effects of exercise on brain health as well as M&L have been discovered with research on animals (Voss et al., 2011). One of those molecules is the BDNF, which is considered a critical factor in the benefits of exercise on L&M (Bekinschtein et al., 2011; Hillman et al., 2008; van Praag, 2008; Vaynman & Gomez-Pinilla, 2006; Voss et al., 2011). BDNF is produced throughout the brain, with high concentrations in the hippocampus, and the majority of empirical evidence shows that its accumulation is elevated with aerobic exercise (Vaynman & Gomez-Pinilla, 2006). BDNF "is associated with aerobic exercise-induced increases in long-term potentiation (LTP), which facilitates synaptic plasticity" (Voss et al., 2011, p. 1509). The newly formed cells of the hippocampus have a lower threshold for excitability, meaning that LTP and consequently exercise-induced synaptic plasticity are facilitated (Cotman, Berchtold, & Christie, 2007). Additionally, BDNF is necessary for the growth and survival of new neurons (Hillman et al., 2008). In sum, exercise regulates BDNF concentrations, which in turn stimulates neurogenesis and synaptic plasticity, and therefore has a profound effect on M&L. Insulin-like growth factor 1 (IGF-1) and vascular endothelial growth factor (VEGF) (Hillman et al., 2008) are two further neurotrophic factors "produced in both the central nervous system and the periphery in response to exercise training" (Voss et al., 2011, p. 1509). IGF-1 and VEGF promote neurogenesis as well as angiogenesis (van Praag, 2008), and IGF-1 in particular mediates the effects of BDNF (Voss et al., 2011).

Animal research has revealed that exercise has multi-dimensional effects on the brain (Berchtold, Castello, & Cotman, 2010) that reveals crucial information that can be taken into account to better understand the mechanisms underlying the effects of aerobic exercise in humans. A good example arises from the study conducted by Roig et al. in 2012, where a single bout of exercise performed immediately after learning a task sufficed to enhance the consolidation of motor memory. This beneficial effect on the long-term retention of the skill could possibly be related to higher levels of BNDF following the exercise.

Human studies equally use neuroimgaing and neuropsychological tests to evaluate the effects of exercise on cognitive performance as well as on brain function and structure. It has been reported that exercise-induced changes in cerebral blood flow observed on MRI could be an “indirect measure for neurogenesis in humans” (van Praag, 2009, p. 287). Additionally, when comparing individuals with high and low fitness levels, another study using MRI showed that higher fitness levels were associated with bigger volumes of prefrontal and temporal grey matter, which predict higher cognitive performance in older adults (Gordon et al., 2008). Moreover, empirical evidence from epidemiological and intervention studies points out that exercise is beneficial at all stages of life even though there is a lack of literature in young adulthood because “cognitive health peaks during young adulthood, suggesting that there is little room for exercise-related improvement to cognitive function” (Hillman et al., 2008, p. 60). This mind-body association is shown in older adults with early findings indicating that people who were regularly active had faster simple and choice reaction times than their inactive counterparts (Hillman et al., 2008). More recent randomised intervention studies with adults generally aged between 60 and 85 years have equally demonstrated that PA training has a positive influence on various cognitive processes with specific larger effects on executive functions such as working memory, action planning, multi-tasking, etc. (Colcombe & Kramer, 2003). When it comes to children, a meta-analysis showed a beneficial relation between PA and performance on various cognitive tasks (i.e., perceptual skills, intelligent quotient, achievement, verbal tests, mathematic tests, developmental level, etc.) with the exception of memory (Sibley & Etnier, 2003). Most importantly, evidence shows that an early onset of active behaviour is ideal as it promotes maintenance and improvement of brain health and function throughout the lifespan (Hillman et al., 2008). Nonetheless, many studies advocate that participation in aerobic exercise beginning in later life equally benefits the brain and cognition (Voss et al., 2011).

To summarize, the evidence drawn from both human and animal studies underlines the importance of regular exercise for M&L. Through neurotropic factors (i.e., BDNF, IGF-1 and VEGF) that facilitate neurogenesis, angiogenesis and consequently synaptogenesis, cardiovascular exercise improves M&L as well as other cognitive functions. In other words, exercise is the most effective behavioural intervention to enhance brain activity and counteract natural age-related decline in cognitive function as well as the ongoing health downfall caused by the sedentary lifestyle adopted by the industrialised world.

b. Factors that hinder memory and learning: interference

Once the practice of a motor skill ends, various neural processes involving synaptic plasticity continue to evolve so as to consolidate the memories of the practiced skill. Indeed, Lundbye-Jensen et al. (2011) speculated that consolidation involves long-term stabilisation of the synaptic changes that were induced in specific neural circuits during the encoding phase. Offline learning enables performance enhancement and renders memories resistant. The observed improvement in performance which should ultimately lead to learning, can last hours to days after the initial training of the motor task (Lundbye-Jensen et al., 2011). As a consequence, this time frame is critical for solid memory consolidation and if it is not respected memory formation can be hindered. Interference is considered to be one of the factors that can negatively alter this central offline treatment. Although the human brain is capable of memorising a great number of motor skills, the learning process can be obstructed by the subsequent learning of other motor tasks. The evidence drawn from many studies that used competing motor learning, pharmacological interventions and repetitive transcranial magnetic stimulation (rTMS) protocols points out the extent of interference on motor learning of an initial task (Lundbye-Jensen et al., 2011).

In some cases, if a second task is learned while the first task is still fragile, interference (i.e., retrograde interference) occurs and learning of the first skill is hindered (Brashers-Krug, Shadmehr, & Bizzi, 1996). Whereas, if a sufficient amount of time (i.e., approximately 6 hours) is left between the two opposing tasks, the first has enough time to become stable and interference no longer disrupts memory (Caithness et al., 2004). Retrograde interference disturbs early memory consolidation and consequently impairs motor learning of the initially practiced skill (Kantak & Winstein, 2012; Lundbye-Jensen et al., 2011). Here, “the motor output for the second task interacts with the motor representation of the previously learned task” (Lundbye-Jensen et al., 2011, p. 1). These findings are consistent with the consolidation window hypothesis. However, this hypothesis exhibits controversy as there is empirical evidence suggesting that by recalling or rehearsing a previously consolidated memory, it is rendered fragile again and therefore becomes susceptible to interference once more (Walker, Brakefield, Hobson, & Stickgold, 2003).

In circumstances where both tasks are similar or derived from one another, interference can occur even when the learning of the second task takes place on the following day (Lundbye-Jensen et al., 2011). Here, interference persists beyond the critical time for consolidation and seems to be mediated by anterograde mechanisms. Anterograde interference (i.e., learning a first skill interferes with the subsequent learning of a second one) involves “persisting neural representations of previously learned skills in the primary motor cortex” (Cothros, Kohler, Dickie, Mirsattari, & Gribble, 2006, p. 2167). These persisting neural representations hinder the ability to acquire other neural representations for the new motor skills and therefore prevent the information from being encoded and retained.

In 2011, Lundbye-Jensen and colleagues conducted a study with the goal to discover what factors determine the occurrence of interference during motor leaning. To do so, they led five experiments involving a total of 12 groups and different conditions. All participants learned a ballistic force task and, in between sets, according to the group they were assigned to, they had to perform an accuracy task (that involved agonist or antagonist muscles and that did or did not include learning), had to rest, sustained rTMS or had electrical stimulation to a peripheral nerve. The first experiment involved learning an accuracy-tracking task either with the agonist muscle (Group 1) or the antagonist muscle (Group 2) (Fig. 9). Here, they discovered that interference only occurred in the group that performed the accuracy task by using agonist muscles and identical movement direction. Thus, they concluded that interference only occurs when the same neural networks are involved in both tasks. The second experiment showed that ballistic motor learning consolidates over time and is enhanced if the initial learning phase is prolonged. During the third set of tests, it was proven that interference with the retention of learning does not occur if the second task is a simple task that does not involve learning. Then, in the last two experiments (four and five), they showed that rTMS to the corticospinal motor output and repetitive electrical stimulation to the peripheral nerve innervating the trained muscle caused interference only if the stimulation was above the movement threshold. In contrast, when the antagonist muscle was stimulated (either by rTMS or with nerve stimulation) or when the intensity was below threshold, no interference occurred. These last findings support the results obtained in experiment one.

In conclusion, interference is very specific and only occurs if the second task is unfamiliar, if learning actually takes place and if the same movement direction and/or identical muscles are involved. In other words, the learner must engage in skill acquisition that induces activation and changes in the neural circuits that were already involved in the first task.

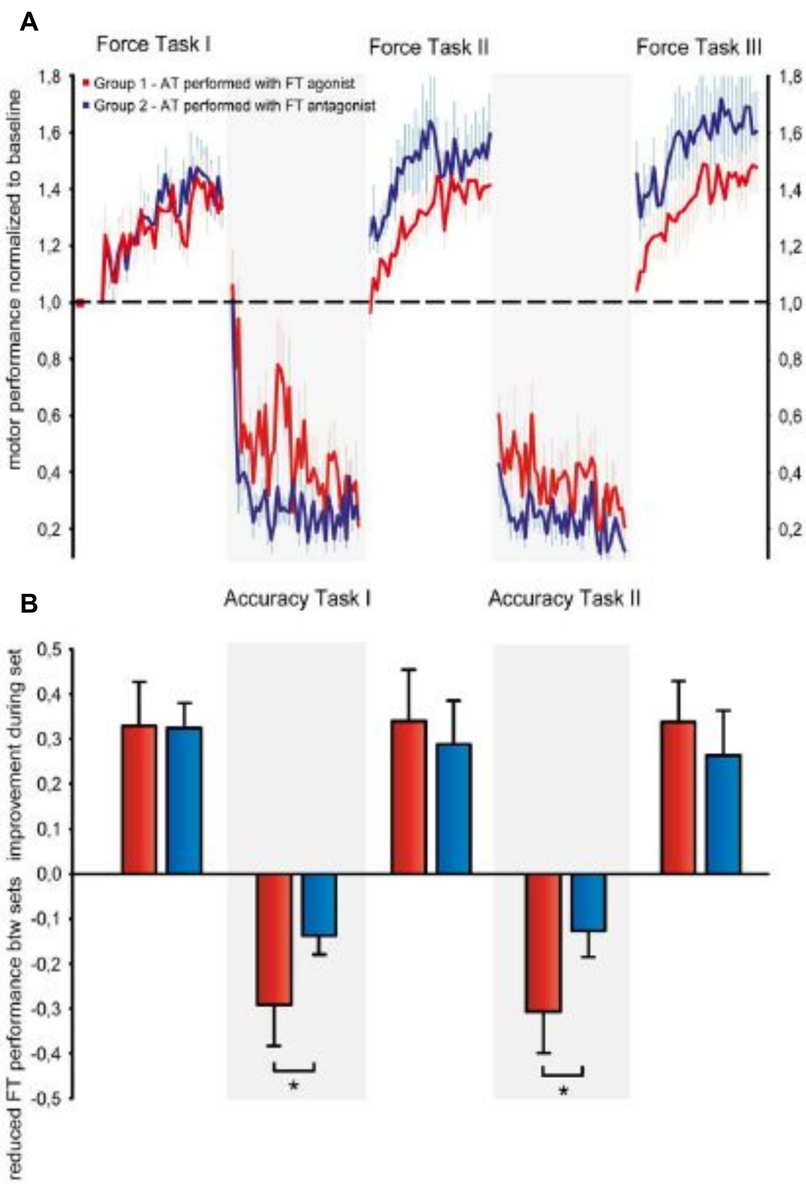


Fig. 9: Interference is specific for direction of movement and agonist muscle. Reprinted from "Interference in Ballistic Motor Learning: Specificity and Role of Sensory Error Signals", by J, Lundbye-Jensen, T.H, Peterson, J.C, Rothwell, & J.B, Nielsen, 2011, *PLoS One*, *6*(3), p.4. Copyright (2011) by Lundbye-Jensen et al.

A. The ballistic force task (FT) was performed as plantar flexion whereas the accuracy task (AT) involved either plantar flexion (Group 1 – red) or dorsiflexion (Group 2 - blue). Motor performance was normalized to the initial ballistic force and deviation from optimal tracking target respectively. During practice participants increased ballistic force in FT and decreased deviation in AT. Curves represent group average motor performance and error bars are standard error of the mean **B.** Increase in FT motor performance during FT practice and decrease in FT performance during AT practice. Bars represent group average ± standard error of the mean. Significant difference ($p<0.05$) in Bonferroni corrected tests were found in the AT performance (*) as only group 1 (red) which performed both FT and AT with the plantar flexor muscles showed strong interference with the FT.

1.2. Context and initial situation

As previously discussed, there is a growing body of literature supporting the impact of cardiovascular exercise on cognition, executive functions, M&L as well as its capacity to decrease risk for dementia and cognitive decline. Moreover, this type of exercise can promote brain health and has a mild positive relation to academic performance in school-children (Hillman et al., 2008). Altogether, aerobic exercise appears to be human’s best mean of prevention against many modern diseases and normal age-related declines.

To date, the relationship between exercise and M&L has not yet been extensively investigated. Although empirical evidence exists, the review discussing the effects of cardiovascular exercise on human memory by Roig and colleagues (2013) shows that its influences are not fully established. Due to the contrasting results (i.e., improvements, impairments or no effects at all) shown in many different studies, it appears difficult to formulate precise conclusions (Roig et al., 2013). The observed discrepancies arise from the methodology (i.e., intensity and duration of exercise regimes) used in the study designs (Audiffren, 2009) as well as the type of memory that was assessed. Indeed, the numerous studies that have been conducted to date assessed various types of learning such as the formation of motor memory, verbal and auditory memory, as well as other cognitive tasks which renders their comparison remarkably difficult. Furthermore, the global definition of aerobic exercise (also called cardiovascular exercise), “an exercise programme that incorporates activities that are rhythmic in nature, using large muscle groups” (Warburton et al., 2006), leaves room for the implementation of numerous different exercise regimes. Consequently, the study designs most commonly involved acute (i.e., a single bout of exercise) or long-term (i.e., repetition of single bouts of exercise over time, lasting from weeks to years) aerobic exercise (Audiffren, 2009; Roig et al., 2013) with varying intensities. Additionally, several other moderators such as duration of cardiovascular programmes, mode of exercise (i.e., cycling, walking, running, etc.), fitness level, age (Roig et al., 2013), difficulty of the assessed task (Berchtold et al., 2010) and genotype (Hopkins, Davis, Vantieghem, Whalen, & Bucci, 2012) equally impact the effects of exercise on memory. Thus, according to the chosen cardiovascular intervention and the influence of the various moderators, different physiological and neurobiological mechanisms are triggered causing disparate effects on assessed type of memory (Hopkins et al., 2012; Roig et al., 2013).

Firstly, single bouts of cardiovascular exercise mainly have an acute effect. The physiological and biological changes that are induced by single bouts appear almost immediately once the exercise has begun (seconds to minutes) and the effects dissipate quite rapidly following exercise cessation (minutes to hours) (Audiffren, 2009; Chang, Labban, Gapin, & Etnier, 2012). Additionally, the brain mechanisms underpinning these transitory effects are considered to be a modulation of the activity of the neural networks involved in the practiced task (Audiffren, 2009). In other words, the changes are functional, not structural. When it comes to memory, it was found that there is a strong temporal relationship between acute exercise and memory formation (Roig et al., 2012). According to when the activity is performed in relation to exposure to the task (i.e., before, during or after), a single bout of exercise facilitates either encoding or consolidation of memories by affecting their underlying molecules (e.g., BDNF, dopamine, epinephrine, etc.) and molecular mechanisms (e.g., LTP) (Roig et al., 2013). Most studies concluded that improvements in long-term memory are greater when the bout of exercise is performed before exposure and consolidation (Labban & Etnier, 2011). These results are mainly achieved through the influence of exercise on the mechanisms involved in encoding of memory traces and perhaps also on the initial stages of memory consolidation (Roig et al., 2013). However, it was recently discovered (Roig et al., 2012) that performing an acute bout of exercise during the consolidation phase (i.e., after exposure to the learned task) facilitates the transfer of the memory trace into long-term memory by acting on consolidation mechanisms and, as a result, improves learning of the skill. This was observed with a delayed retention test which, as mentioned in a previous chapter (see 1.1.4 Motor skill learning), is “a better indicator of learning than performance at or shortly after acquisition” (Roig et al., 2012, p. 5). In contrast, acute exercise has not shown to significantly improve the performance on short-term retention tests. This can be due to the proximity between the retention test and the end of the bout of exercise, where performance could have been hindered by fatigue, above baseline arousal (Labban & Etnier, 2011) or insufficient amount of time for consolidation to take place (Roig et al., 2013). To summarize, acute bouts of exercise have a small time-dependent facilitative effect on short-term memory and a relatively large positive time-dependent influence on the long-term retention of memories.

Secondly, the changes induced by regular physical exercise tend to appear up to several weeks following the beginning of the exercise programme and are sustained for numerous weeks once it ends (Audiffren, 2009). Moreover, the chronic biological and physiological effects induced by long-term exercise are caused by positive neurophysiological adaptations involving durable structural and functional changes in brain areas that support memory formation processes (Audiffren, 2009; Roig et al., 2013). This being said, the actual effects of regular exercise on short and long-term memory are modest. Still, studies show that the cumulative effect of each bout of exercise composing the long-term intervention has an important role in maintaining the molecular and structural mechanisms involved in memory processing (Roig et al., 2013). In addition to the well-known positive effects regular cardiovascular exercise has on well-being, the higher fitness levels achieved through long-term exercise tend to show some positive effects on M&L (Roig et al., 2013). In sum, regular physical exercise leads to indirect influences on memory processing by inducing various adaptations in the brain.

Altogether, empirical evidence shows that acute and long-term physical exercise affect memory in different ways, but the appropriate combination of these two strategies can lead to a greater enhancement of the global effects of cardiovascular exercise on human memory (Roig et al., 2013).

Subsequently, the present study was created so as to determine the effect of the combination of acute and long-term cardiovascular exercise on motor memory. This type of memory was chosen following the recent new findings of Roig and co-workers (2012) who investigated the potential effects of an acute bout of exercise on motor skill learning. Their study revealed the importance of the timing of the exercise bout in relation to the practice of the motor task and shed new light on the positive effects of this exercise strategy on the long-term retention of the practiced skill. In other words, they discovered that the long-term retention of the learned task (i.e., a visuomotor accuracy tracking task) was most effective when the acute bout of exercise (i.e. 12 min of cycling at relatively high intensity) was performed during the early phases of consolidation (i.e., directly after practice of the accuracy task) and that a delayed retention test (i.e., 7 days after practice) is necessary to determine the full effects of the exercise bout on the long-term memory (and ultimately learning) of the task (Fig. 10). Thus, the interesting results exposed in their work set the foundation for the design of this study.

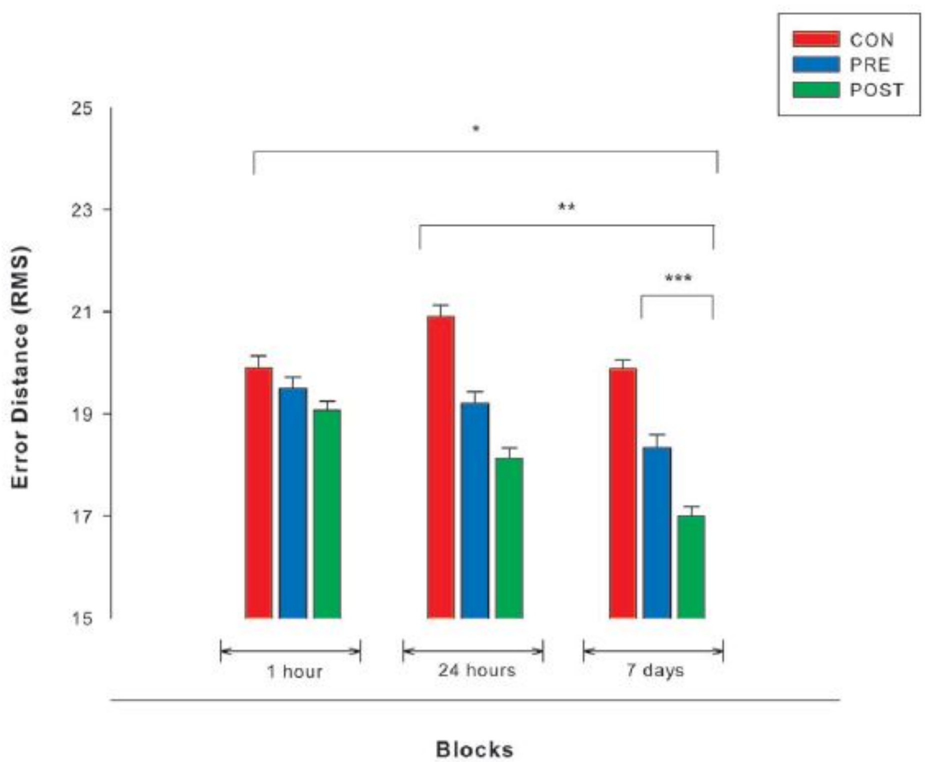


Fig. 10: Performance of the visuomotor accuracy-tracking task (AT) during retention. Reprinted from “A single Bout of Exercise Improves Motor Memory”, by M. Roig, K. Skriver, J. Lundbye-Jensen, B. Kiens & J.B. Nielsen, 2012, *PLoS One*, *7*(9), p.6. Copyright (2012) by Roig et al.
Performance was measured as the average root mean square (RMS) value of the error distance between the participant’s torque signal and the displayed target. Overall differences among groups in the retention of the motor skill were found (*). The group that performed the exercise bout before learning the AT (PRE) and the group that performed it after the AT (POST) showed better retention of the motor skill than the control group (CON) 24 hours and 7 days after practice (**). POST also showed better retention than PRE 7 days after practice (***). Data are presented as means and error bars are standard error of the mean. All comparisons yielded a p value <0.001.

Although most of the studies researching the effects of cardiovascular exercise on memory and other cognitive functions typically chose walking, cycling or running, a totally new mode of exercise was selected for this study. Indeed, the SensoProTrainer® (SPT; Fig. 11) was the chosen exercising device. This new training device has only just been put on the market (summer 2013) and, so far, no scientific studies exploring the potential effects of training programmes have been conducted. A more extensive description of the SPT will follow in the chapter discussing the methods used in this study.

Fig. 11: SensoProTrainer®

1.3. Goal and research question

On the basis of the interesting findings of Roig and his colleagues (2012) and the conclusions drawn from the meta-analysis of the literature on the potential effects of acute and long-term cardiovascular exercise on different types of memory, the goal of this research is to determine whether an acute bout of intense exercise performed immediately after practicing a visuomotor accuracy-tracking task (AT) and a four week training programme (three sessions a week) on the SPT have a positive effect on the consolidation of motor memory. Therefore, the aim was to investigate whether the strategic combination of these two cardiovascular regimes has the potential to significantly improve the long-term retention of the practiced AT. Motor memory consolidation is therefore assessed at two time points: (1) during the pre-tests (i.e., before the four week intervention); (2) during the post-tests (i.e., after the four week intervention).

The questions that need to be answered are the following: (1) Does an acute bout of exercise on the SPT performed by an intervention group (IG) immediately after learning a motor task have the ability to significantly improve the consolidation of motor memory in comparison to a control group (CG)? ; (2) If so, can a four week training programme on the SPT performed by an IG further enhance the consolidation of motor memory? It was hypothesised that by performing an acute bout of exercise after practicing the AT, the IG will better enable their long-term retention of the learned motor task whereas the CG would not. The effect of the acute bout of intense exercise should immediately be noticeable through a greater performance of the IG on the delayed retention test (7 days after learning the task) before the four week training programme. Furthermore, we hypothesised that the improvement in fitness level of the IG achieved with a four week training programme would further enhance the expected differences in motor memory consolidation between IG and CG. The performance on the deferred retention test after completion of the training intervention should get even better due to higher fitness levels.

2. Methods

This methods chapter will begin by presenting the participants that took part in the study and a detailed description of the SPT with its various training possibilities will follow. Then the study design, as well as the AT, the HIT, the graded cardiovascular exercise test and the various training sessions of the four week intervention will be fully described. Finally, the data analysis and statistical methods are presented.

2.1. Participants

A total of thirty right-handed male and female participants were invited to take part in this study through the medium of recruitment emails and flyers written in English, German and French (Appendix A). Inclusion criteria for participation were the following: aged between 18-30 years, healthy and hardly active on a daily basis (i.e., <150 min of sport per week). Any orthopaedic, neural or heart problems would have automatically excluded anyone from the study, but no such problem appeared. All the information concerning the volunteers was self-reported as no fitness evaluations or questionnaires were organised prior to the pre-tests. The participants were divided into two groups: IG (eleven female and four male) and CG (eleven female and four male). Table 1 gives a description of each group's specific characteristics. An information document (Appendix B) concerning the goals of the research as well as the study duration and organisation was given to all participants in their mother tongue. Additionally, the pamphlet clearly described all tests and briefly explained the training sessions on the SPT. A consent form (Appendix C) was individually signed before beginning the research.

Table 1

Group characteristics

	IG	CG	TOTAL
n	15	15	30
Sex (F/M)	11/4	11/4	22/8
Age (years)	22.87 (20-30)	23.53 (19-28)	23.20 (19-30)
Height (cm)	173.2 (164-190)	167.93 (148-190)	170.57 (148-190)
Weight (kg)	68.57 (53-105)	64.4 (50-90)	66.48 (50-105)

Comments. Values are presented as means and ranges. n=number of participants. F=Female. M=Male.

2.2. SensoProTrainer® (SPT)

The SPT was chosen as the mode of exercise for this study due to collaboration between the University of Fribourg and the developers of the device. The potential of this training device has already been recognised at FIBO (leading international trade show for fitness, wellness and health) in Cologne when it was nominated for the 2013 innovation award in the category “health promotion” (Schmocker, Mumenthaler, Orzechowsk, Fahrni, & Urfer, 2013). However, no scientific studies exploring the machine’s effectiveness have yet been conducted, rendering the findings of the present study relatively novel and potentially quite interesting. Moreover, the adaptations to training on SPT revealed in this study will be used to give the company recommendations for the development of effective training strategies.

The SPT was developed by a company called Sport-Point GmbH based in Gimmis (Switzerland) and owned by four people (Urfer, 2013). The idea for this project materialised six years ago and since then many prototypes were built and implemented (Urfer, 2013). The design used for this study is called SPT 1000 LUNA and is illustrated below (Fig. 12).

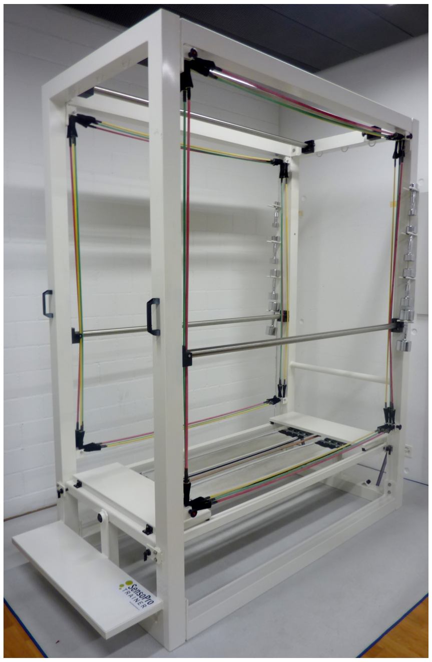


Fig. 12: SPT 1000 LUNA at the University of Fribourg, Switzerland.

The main metal structure supports a swingboard (Fig. 13A) composed of two bands composed of a trampoline-like material and a slackline (fixed between the two bands) on which athletes perform their workouts (jogging, running, bouncing or balancing). The swingboard remains fixed or is rendered mobile (Fig. 13B) by releasing the four screws that hold it in place. Furthermore, the mobility of the swingboard can be tailored to individual skill level by adding or removing rubber bands named “friends” found at one end of the device (Fig. 13C). Two rails are positioned on both sides of the structure to insure better security and/or provide stability while performing the many possible drills. These can be removed for more convenience. In addition to the basic constitution of the device, three rubber tubes of different colour (i.e., yellow, green and red) and resistance (yellow is the weakest and red is the strongest) are attached to each side of the main structure (Fig. 12) so as to give the participant more possibilities for cardio or strength workouts. Free weights are equally provided on the device for use during training sessions (Fig. 13D).

All in all, this multifunctional device is suitable for beginners as well as advanced individuals and offers many different workout options such as cardio, balance, coordination and strength training, while giving them an entertaining twist.

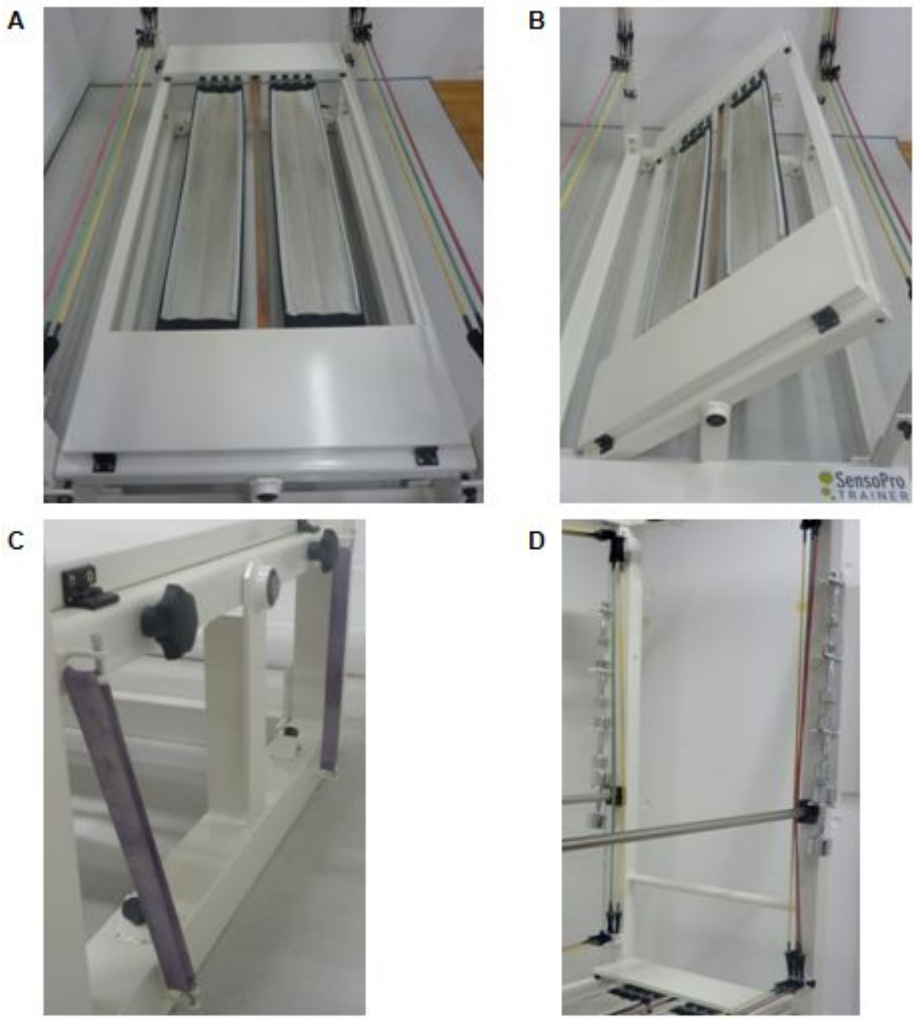


Fig. 13: SPT 1000 LUNA components. A. Fixed swingboard. **B.** Mobile swingboard. **C.** “Friends” that can be added or removed to tailor the mobility of the swingboard to the athletes’ skill level. **D.** Free weights and rubber tubes for workouts

During the acute bout of exercise and the four week intervention programme, participants of the IG performed their training on the SPT. They were asked to jog, bounce or balance on the bands or the slackline, while the swingboard was either fixed or mobile. Additionally, they had to use the rubber tubes positioned in front, behind and above them. These exercise sessions will be fully explained in a subsequent chapter.

2.3. Study design

The experiment that was organised within the context of this Master's Thesis is a randomised controlled trial. Figure 14 illustrates the different phases of the research.

The pre-tests were organised on a total of three days. The participants individually came to the laboratory on day one to begin the experiment. In order to measure their capacity to acquire a motor skill, they performed the first AT (AT1) learning phase. This period was composed of six blocks (6x3 min) with a short break allocated between each block. After acquiring this initial AT, participants of the IG were taken to the fitness room in a neighbouring building to complete a 12 min high intensity training (HIT) on the SPT. They then returned to the laboratory for the AT retention test (RET1) which took place precisely 30 min after acquisition of the task. In contrast, the participants of the CG were instructed to rest for 30 min after the motor skill practice. During this time, they were requested to sit quietly but were allowed to read. In turn, they performed RET1. This first retention test was organised in order to determine the potential short-term effects of the HIT on the retention of the AT.

On day two, the possible long-term retention of the motor skill was measured with a retention test 24 hours (RET2) after the learning phase. Both IG and CG took part in this test which was composed of two blocks (2x3 min) of the same AT. Following RET2, all participants' fitness level was evaluated with a graded cardiovascular exercise test on the treadmill.

One week after their first visit to the laboratory (i.e., day three of the pre-tests), all participants individually reported back to the laboratory to undergo their final retention test (RET3) equally composed of two blocks of three minutes. This last retention test would also allow the evaluation of the potential effects of the HIT on the long-term retention of the task.

Following the pre-tests and during the next four weeks, the participants of the CG returned to their normal daily activities. On the other hand, the IG began a four week intervention period immediately after the RET3. They took part in a training programme on the SPT at the rate of three sessions a week. This programme was composed of a combination of cardiovascular and balance exercises and was conceived in order to elevate the level of difficulty every week.

Finally, the week following the intervention period all participants were re-tested. The organisation, sequence and measurements were identical to the first three days of testing. However, for these post-tests, a modified AT (AT2) challenged the participants. Additionally, the HIT difficulty was heightened. An in-depth description of the AT, the HIT and the training programme will follow in the next chapters.

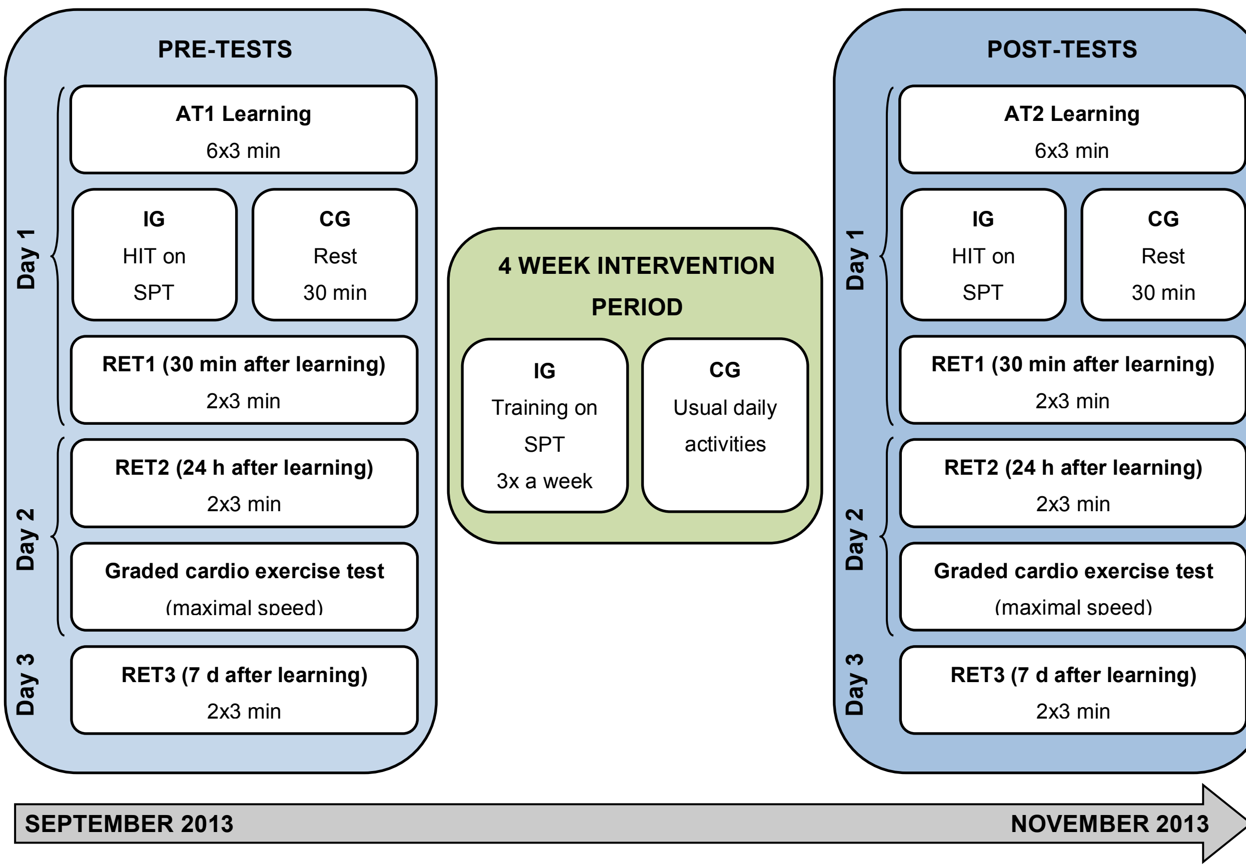


Fig. 14: Study design representing the different phases of the experiment.

2.4. Visuomotor accuracy-tracking task (AT)

In order to perform the AT, participants were seated in a desk chair at a table on which the computer screen was placed (Fig. 15A). They rested their right arm on three soft foam pads (placed on top of each other) with their index finger touching the lever positioned behind the arm support structure (Fig.15B). The lever was connected to a force transducer (AMTI MC3A-500; Advanced Mechanical Technology, Inc.; Watertown, USA) which provided information on the force applied with the index finger while tracking the displayed curve. The force signal's sampling frequency was set at 250 Hz. Data was saved to a computer using recording software (Pfitec, Imago Record; Endingen, Germany).

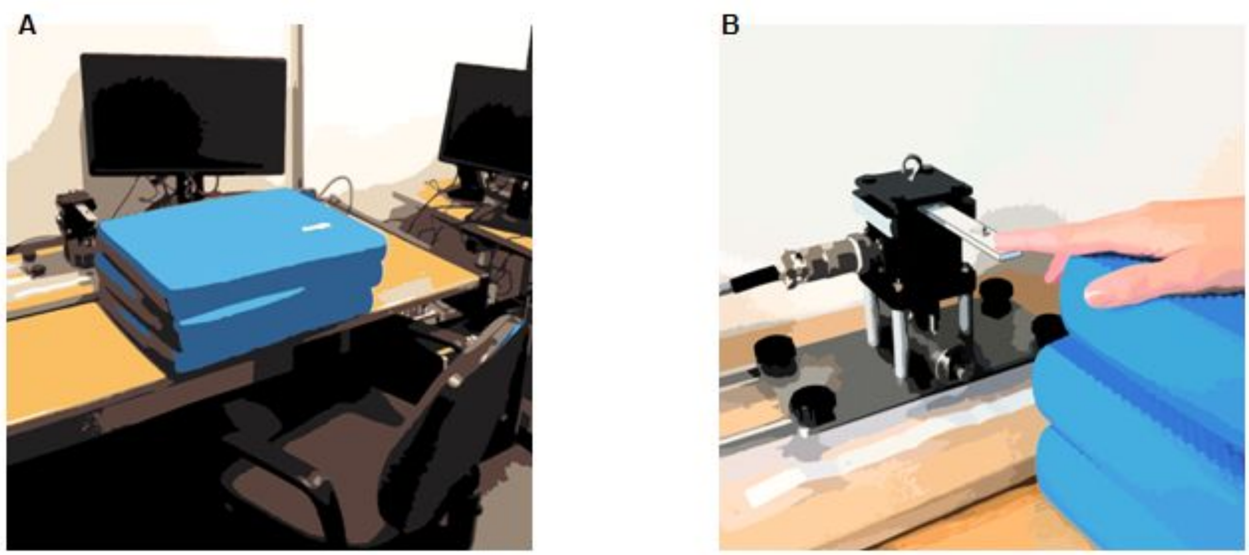


Fig. 15: The visuomotor accuracy-tracking task (AT). A. Setup for the AT. **B.** Arm and hand support structure with finger place on the lever.

The AT used for this study was designed by Mr. Martin Keller, co-supervisor of the research. LabView based software (Pfitec, Stimuli; Endingen, Germany) was utilised to create the reference sinusoid curve that would have to be tracked. Once the trigger was launched on the programme, the reference wave (shown in black) moved at a constant velocity across the screen from left to right and was repeated several times so as one block lasted three minutes.

Before beginning, experimenters made sure that participants were comfortable. Then, they instructed the participants on how to perform the AT, but no test trials were allocated. They were asked to track the reference curve as accurately as possible, meaning they had to keep the red signal (i.e., their actual track representing the force applied on the lever) as close to the target black curve as possible. To do so, they had to apply more or less strength to the lever in order to move the red marker upwards or downwards to follow the reference curve (Fig. 16). Obviously, participants could always see the distance separating their actual trace (red) and the reference wave (black) informing them of their performance. However, no further precise feedback was given. This AT was performed in a quiet environment to ensure that participants would remain fully concentrated throughout the task, as accuracy was of the upmost importance.

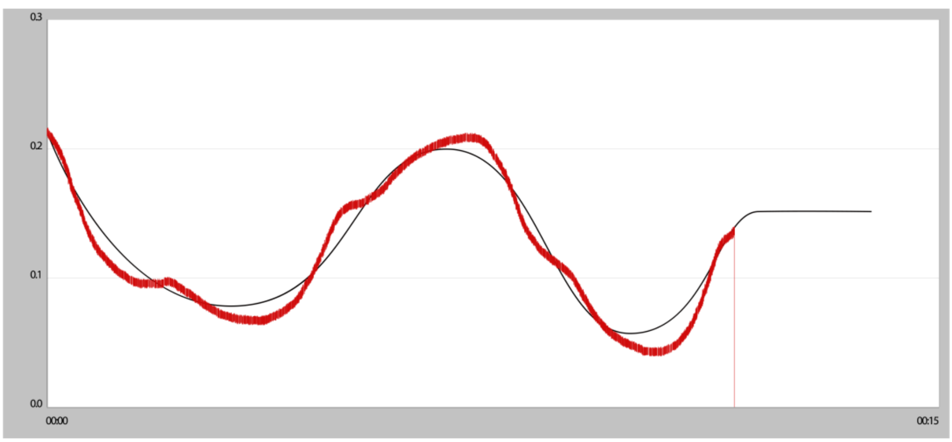


Fig. 16: AT shown on the computer screen. The participants had to track the AT reference curve (black) by applying more or less pressure to the lever. Their actual track (i.e., their force signal) is shown in red.

As mentioned in the previous chapter (see 2.3 Study design), participants took part in an initial learning phase during which they performed AT1 for a total of 18 min (6x3 min) with a short break between each 3 min block. This stage of the experiment permitted the determination of the participants' capacity to acquire the motor skill. The retention tests, which were undertaken 30 minutes, 24 hours and 7 days after the AT learning phase, lasted 6 min each (i.e., 2x3 min). These phases were identical during both the pre- and post-tests sessions. However, the curve for the AT was changed from AT1 to AT2 so that the participants would be newly challenged. As a result, new learning should occur and all potential influence of previous learning would be ruled out. During the pre-tests, one block (i.e. 3 min) was composed of 6 trials (i.e., 6 repetitions of the curve), whereas one block had 15 trials during the post-tests. Thus, the number of trials the participants performed varied between the two testing sessions with a total of 72 trials for the pre-tests and 180 for the post-tests.

AT performance for all phases of the experiment (i.e., AT learning, RET1, RET2 and RET3) was determined during the off-line analysis of the saved data. It was calculated as the root mean square (RMS) of the error distance between the participants' force signal and the reference curve across all sampled data points for each trial. In other words, the error distance for each data point was calculated using the square root of the square of the difference between the desired value and the actual value. For each trial, these new values were added to each other to obtain a sum of the errors. Finally, an average of the respective trials for the AT learning phase, RET1, RET2 and RET3 was calculated so as to obtain the AT performance for each phase of the study.

2.5. High Intensity Training (HIT) on SensoProTrainer®

HIT is defined as a type of "physical exercise that is characterised by brief intermittent bursts of vigorous activity, interspersed by periods of rest or low-intensity exercise" (Gibala, Little, Macdonald, & Hawley, 2012, p. 1077). This form of exercise was chosen for its many possibilities in combining duration and intensity of intervals and for its ideal fit for this study. Firstly, according to the review written by Roig et al. (2013), an acute bout of exercise has the largest effect on short- and long-term memory if its duration is short (<20 min). Secondly, the same review demonstrates that low intensity has the strongest effect on short-term memory, whilst exercise intensity has little impact on long-term memory. Here a slight controversy arises with the definition of HIT. However, this project is based on the study conducted in 2012 by Roig et al. in which the authors chose an exercise protocol of relatively high intensity. Therefore, it was decided to use a high intensity protocol as well. By definition, HIT perfectly fits the characteristics of high intensity and short duration.

On day one of both pre- and post-tests, the IG performed the acute bout of exercise on the SPT immediately after the AT learning phase. This exercise consisted of a 12 min HIT that was designed to induce a high level of effort without total exhaustion. Consequently, the contents of HIT programme for the pre- and post-tests were slightly different. Indeed, taking into consideration that the participants would have trained on the SPT during one month at the rate of three practices a week and would have most likely elevated their fitness level compared to the pre-tests, the post-test HIT was adapted in order to guarantee a high intensity bout of exercise. The training protocols are briefly described in the following paragraph.

The pre-test HIT began with a 2 min warm up and was followed by 2x3 min blocks of intensity intervals interspersed with a 2 min recovery block. During the 3 min strenuous phase, a 1 min interval (i.e., 15 s high intensity sprint and 45 s low intensity exercise with the tubes) was repeated three times. The inactive period during which participants were asked to lightly bounce on the bands permitted full recovery from the previous exertion. Following the second 3 min block, another 2 min recovery phase ended the HIT. In contrast, the post-test HIT only allocated 1 min to warm up and the duration of the two high intensity interval blocks was augmented to 4 min. Additionally, the recovery block was marginally harder as the participants had to jog (no longer bounce) so as to recover actively rather than passively. A full description of these two HITs is available in Appendix D.

The HITs were identical for the entire group. However, the exercise intensity was tailored to each participant as it varied according to their respective fitness levels. Moreover, due to the device’s properties, the intensity could not be precisely evaluated and specifically set during the workout. Consequently, the participants were asked to fully exert themselves during the high intensity blocks of the proposed bout of exercise. The lack of specificity of the intensity should not influence the effects of this exercise on the long-term memory of the motor skill as, according to Roig et al. (2013) intensity has little impact on the delayed retention of a task. However, in order to have an idea of the participants' individual workload during the effort, a monitoring system (Polar Team^2 Pro, Polar Electro Oy, Kempele, Finland) recorded their heart rate during the HIT.

2.6. Graded cardiovascular exercise test

Following RET2 on day two of both pre and post-tests, all participants individually performed a graded exercise test on the treadmill (StairMaster, USA). This test was used to determine the participants' fitness level. The exercise protocol and the goal of the test were fully explained to the participants prior to the test. The instructions emphasised the importance of their full exertion.

The initial speed of the treadmill was set at 5.4 km/h. Then, the velocity was elevated by 0.6 km/h every minute. The test was terminated once the participant could no longer run at the given speed. At this point, they were expected to have achieved complete exhaustion. If a participant ran a minimum of 40 s in a stage, the stage was validated and the current running speed was documented. In contrast, if he/she ran less than 40 s in a stage, the speed of the previous stage was retained. The performance on this test was determined by the maximal speed (in km/h) that was reached.

In addition to the reported maximal speed, heart rate data was collected during the test. Before beginning the exercise protocol, participants were given a heart rate monitoring system which was synchronised with the treadmill as well as with the computer software (Polar Team^2 Pro, Polar Electro Oy, Kempele, Finland). Heart rate was manually recorded at rest, at the end of each stage, immediately upon termination of the test, as well as after 1 min and 2 min of recovery. These records were complemented by the computerised heart rate data.

2.7. Training programme on SensoProTrainer®

As described in the study design, the participants of the IG took part in a four week training programme during which they actively trained on the SPT at the rate of three times a week. The workout plan was designed on the basis of a series of exercises and time frames suggested by Mr. Jan Urfer. The proposed variety of drills specifically trained either balance or cardiovascular endurance. Consequently, the programme was organised into three main blocks. Firstly, participants took part in a short 2 min warm up comprising of an alternation between jogging and bouncing. Secondly, they were asked to perform a 9 min balance block consisting of four exercises that evolved every week. Finally, the participants completed an interval training as part of the cardiovascular workout. The duration (12 min and 18 min) and structure (sprint and jogging duration as well as recovery exercises) of this third section varied weekly. The total duration of a training session reached 23 min for the first two weeks and 29 min for the two remaining weeks.

The level of difficulty of each exercise was based on individual skill level. Participants were given the choice of tubes with more or less resistance during cardiovascular interval training and also had the use of the rails during balance exercises if required. Additionally, in order to achieve the best results in both balance and cardiovascular fitness, all drills were identical throughout the three weekly sessions thus leaving room for improvements. However, they were rendered more challenging every week so as to maintain an appropriate level of stress on the body. In other words, once the body had adapted to a certain exercise level, the difficulty was increased so that the strain of the exercise was strong enough to lead to the desired changes. Consequently, four different programmes (one per week) were established (Appendix E). Note that this four week training programme was considered as a long-term cardiovascular exercise intervention.

2.8. Data analysis and statistics

The difference in performance (i.e., maximal speed) between groups on the graded cardiovascular exercise test was compared with a two-way (group x time) analysis of variance (ANOVA). When a significant effect was found in the ANOVA, other pairwise comparisons with student's t-test were performed. Here, Bonferroni's correction was applied to the level of statistical significance.

AT performance during the learning phase of the pre-tests was compared with a two-way ANOVA using time as a within-subject variable and group as an independent variable. Additionally, the presence of learning was determined using the time effect shown in the previous ANOVA. The difference in the retention of the motor skill between RET1 and RET2 was equally compared with a two-way (group x time) repeated-measures ANOVA. Other patterns were determined with student's t-tests. The difference in AT performance at the beginning (trials 1-5) and the end (trials 80-85) of the post-test learning phase was compared with a two-way (group x time) ANOVA and student's t-tests. Statistical significance was set at $p<0.05$. Data was presented in the graphs as means with standard error of the mean.

The data collected with the heart rate monitoring system during the different phases of the experiment was not analysed. It was only used to supervise intensity of effort during the HIT, the graded cardiovascular exercise test and the training sessions of the intervention phase.

Note that the previous statistical data analyses were performed with advanced statistical analysis software (IBM SPSS Statistics Version 20, IBM Cooperation, New York, USA). On the other hand, a spreadsheet programme (Microsoft® Office Excel®; Redmond, USA) was used to create graphs and carry out student's t-tests.

3. Results

The two-way ANOVA of the graded cardiovascular exercise test showed a significant group*time interaction effect [$F(1, 28)=6.24$; $p=0.017$)]. The improvement of the IG's maximal running speed was highly significant ($p<0.001$), whereas changes in CG's performance were minimal and non-significant (Fig. 17).

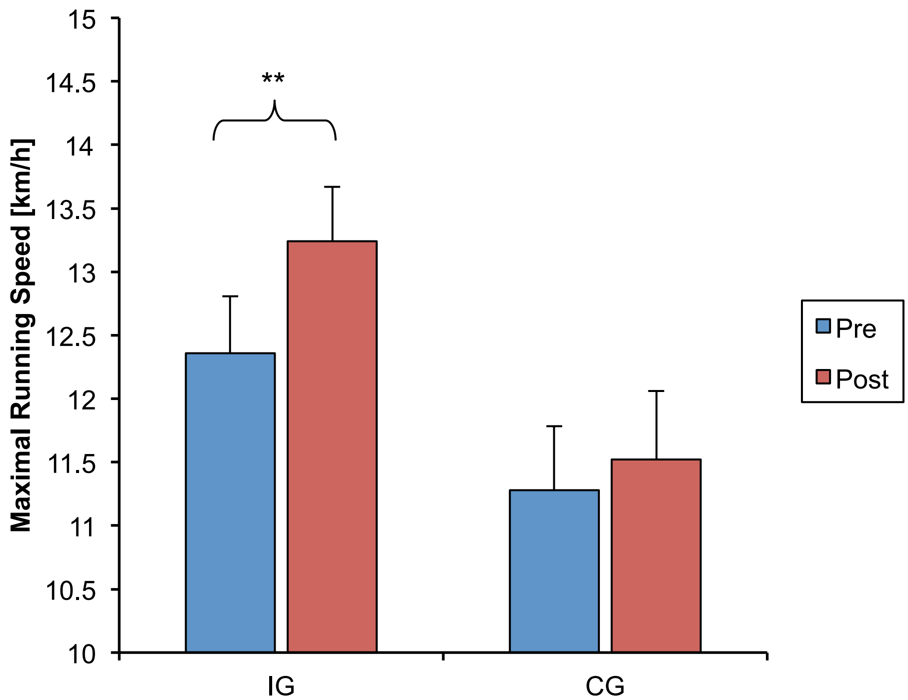
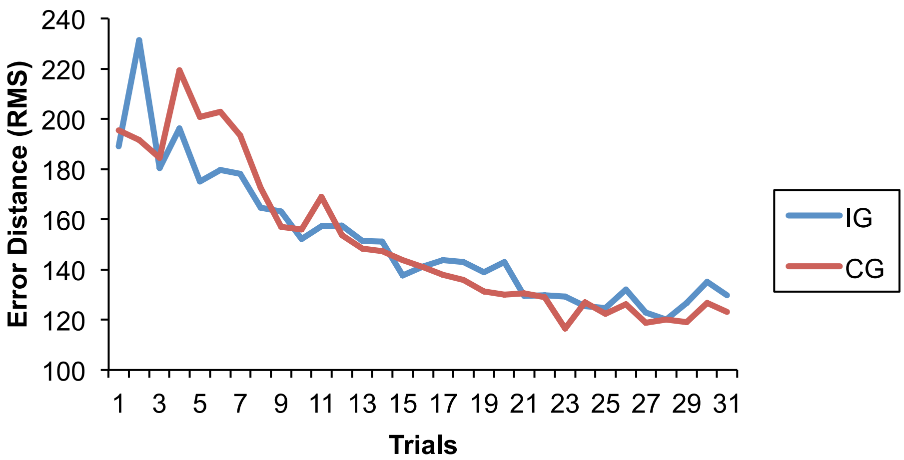


Fig. 17: Performance of the graded cardiovascular exercise test. The performance was measured as the maximal running speed. A highly significant difference ($p<0.001$) in the performance of the IG from pre- and post-tests (Pre: 12.36 ±1.74 km/h; Post: 13.24 ±1.74 km/h) was found (**). Data are presented as means and the error bars are standard error of mean.

The two-way ANOVA of the pre-test acquisition phase showed a highly significant time effect ($p<0.001$) proving that learning occurred for both groups (Fig.18A). Additionally, this ANOVA showed there was no significant group*time interaction effect [$F(30, 780)=9.76$; $p= 0.988$)], meaning that both groups had a similar AT1 performance during this phase (Fig. 18B).

A



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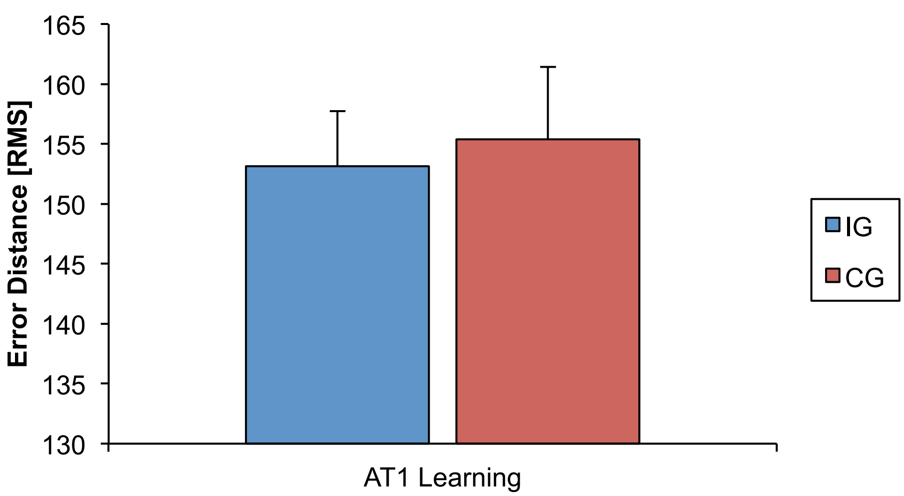


Fig. 18: Performance of the AT1 during the pre-test learning phase (31 trials). The performance was measured as the average root mean square (RMS) of the error distance between the participants' force signal and the reference curve. **A.** Both groups showed learning ($p<0.001$), which is illustrated as the progressive decrease in error distance. Each data point represents the average of each trial. **B.** Both groups showed similar AT performance ($p=0.988$). Data are presented as means of all trials and the error bars are standard error of the mean.

Because of a methodological issue in the study design, the data from RET3 is considered to be biased and, as a consequence, it is ignored for further analysis and the two-way (group x time) ANOVA comparing performance during retention tests only considered RET1 and RET2. This repeated-measures analysis of variance showed no significant difference in the group*time interaction effect [$F(1, 27)=3.99$; $p=0.056$)]. However, because the difference almost reaches statistical significance ($p=0.05$) and figure 19 shows that IG betters its performance from RET1 to RET2, whereas CG gets worse, a student's t-test was performed to prove the apparent tendency. This post-hoc pairwise statistical comparison confirmed that IG's improvement from RET1 to RET2 was significant ($p=0.05$), while the changes in CG's performance remained statistically identical ($p=0.358$).

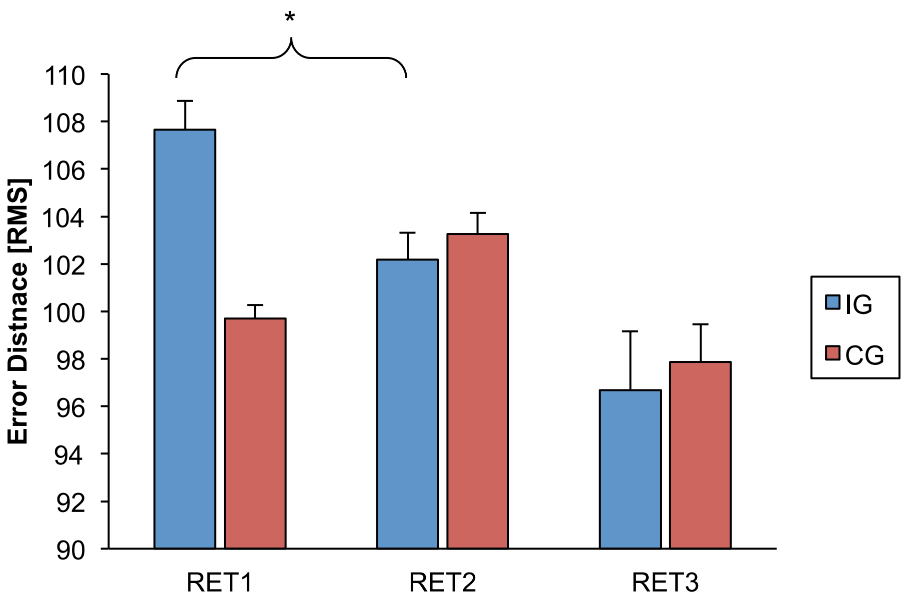
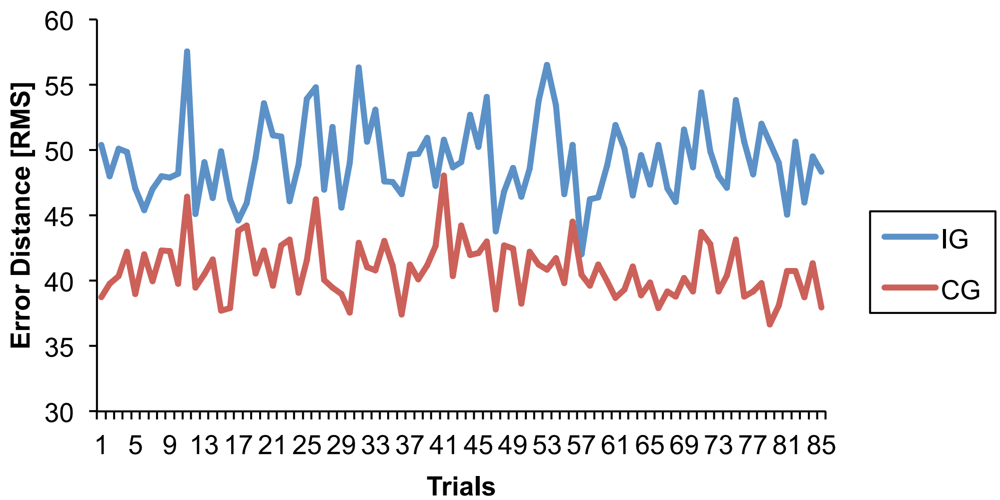


Fig.19: Performance of the AT1 during three retention tests (RET1, RET2 and RET3) of the pre-test session. The performance was measured as the average root mean square (RMS) of the error distance between the participants' force signal and the reference curve. A significant difference ($p=0.05$) between the performance of the IG at RET1 and RET2 was found (*). Data are presented as means and the error bars are standard error of the mean.

During the acquisition phase of AT2 in the post-tests, the data showed that neither IG nor CG learned the new AT (Fig. 20A). The lack of progressive decrease in error distance was proven with a two-way ANOVA comparing the AT performance at the beginning (trials 1-5) and performance at the end (trials 80-85) of the learning phase

(Fig. 20B). This statistical analysis showed no significant time effect (*p*=0.594). In addition, the student's t-test supports this result by showing no significant difference between performances at these two moments for IG (*p*=0.396) nor CG (*p*=0.954). In contrast, there was a significant difference between groups (*p*=0.002, Fig. 20C), with CG performing better than IG.

A



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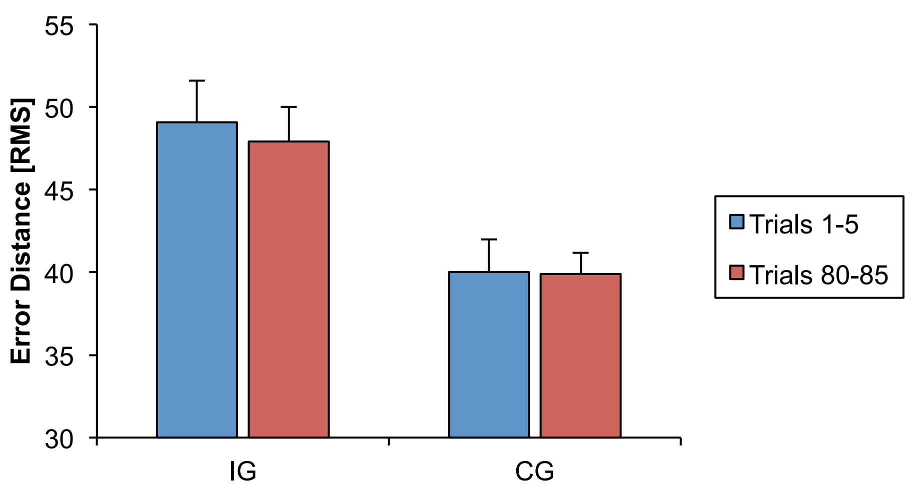

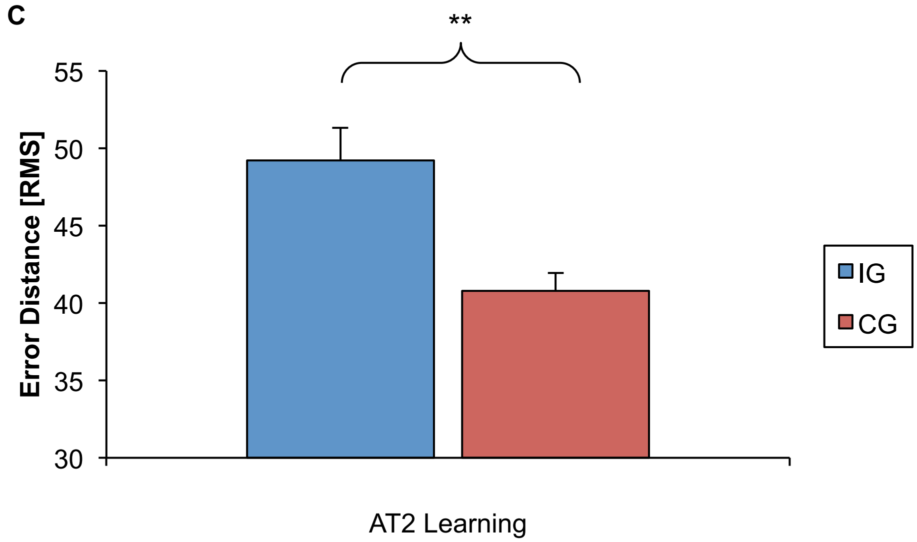

Fig. 20: Performance of the AT2 during the post-test learning phase (85 trials). Performance was measured as the average root mean square (RMS) of the error distance between the participants' force signal and the reference curve. **A.** The lack of progressive decrease in error distance shows that no group learned the AT. Each data point represents the average of each trial. **B.** No significant difference (IG: p=0.396 and CG: p=0.954) in the AT performance between the beginning (trials 1-5) and the end of the learning phase (trials 80-85) was found. Data are presented as means and the error bars are standard error of the mean. **C.** There was a highly significant difference (p=0.002) in AT performance between groups (**). Data are presented as means and the error bars are standard error of the mean.

4. Discussion

The primary purpose of this study aimed to determine whether the promising results shown in Roig et al.'s research (2012) could equally be achieved using a different exercising device (i.e., the SPT). The secondary purpose was to determine whether the combination with a long-term training programme would reinforce the acute effects of the bout of exercise performed after the learning phase. The results do not allow us to answer these two questions with confidence. With regard to the first question, the results suggest that a single bout of exercise has a tendency to promote motor memory consolidation but the full potential was not proven. With regards to the second question, the long-term training intervention successfully elevated the participants' fitness level, however the data does not indicate further enhancement of motor memory consolidation. Thus, on the basis of these findings the two initial hypotheses are rejected. Nonetheless, numerous factors have influenced the poor outcomes that were described in the results section, so we will attempt to provide some possible explanations for the failure in reaching the expected goals. Firstly, by discussing the results achieved following the acute bout of exercise during the pre-tests and secondly, by analysing the data obtained from the incremental exercise test and the tests of the post-measurement session.

Because this study was performed at the same time as another study on the SPT evaluating the effects of the four week intervention on balance and cardiovascular fitness, a methodological problem arose when creating the study design. Indeed, a set of balance tests, the graded cardiovascular exercise test as well as the AT learning phase and three retention tests for the present study had to be planned for all 30 recruited volunteers during both pre and post-tests sessions. On the first day of testing, the participants' balance was measured and the AT learning phase, its subsequent HIT and RET1 were completed. The high physical demands of day one rendered the scheduling of the graded cardiovascular exercise test on the same day impossible. Fatigue would have impaired participants' full capabilities and the test would not have been performed under ideal conditions, thus leading to biased results. Consequently, the incremental cardiovascular test was scheduled for all participants the following day, directly after RET2. However, this was a methodological mistake as it actually biased the results of the present study. During RET2, participants performed the AT for a total of 6 min. Although the goal of RET2 was to evaluate the potential long-term retention of the consolidated skill, it can be considered that this time-frame offered additional practice and further possibility to acquire the task. After RET2, all participants performed the cardio test, meaning that both groups completed an acute bout of exercise immediately after practicing the AT. This implies that the potential exercise-induced long-term memory gains would not only be visible for IG who performed the acute bout of exercise on the SPT after the initial learning phase (on day one), but would equally be present for CG because they exerted themselves on the treadmill after RET2 (on day two). As a consequence, the performance on RET3 is biased. Although, Roig et al. (2012) discovered the largest benefits of the acute bout of exercise specifically in this delayed retention test, no conclusions can be drawn from the results of this test in the present study. However, I would like to clarify that under no circumstance does this diminish the importance of Roig and his colleagues' findings.

This being said, the remaining data of the pre-tests (AT1 Learning, RET1 and RET2) showed a tendency to achieve similar results to the previously mentioned study. Indeed, the two-way ANOVA comparing performance during the acquisition phase demonstrates that both IG and CG learned the task and no significant difference in AT1 performance was noticeable at this stage. When comparing the performance in the other two retention tests with the ANOVA, the difference was almost significant (p=0.056). In addition, a student's t-test showed that IG significantly diminishes its error distance with time whereas CG does not. Moreover, CG's performance actually deteriorates on the day after learning the skill (note that the difference between RET1 and RET2 is not significant), just like the control group in Roig et al.'s study. In contrast, the IG tends to progress to a better level than CG (no significant difference) regardless of its performance being inferior to that of CG during RET1 (no significant difference).

Four possible explanations can be given for IG's poor performance in RET1: (1) Fatigue in the upper limbs caused by the HIT on the SPT requiring many arm movements against resistance. This could have led to diminished fine motor skills required for the AT (Missenard, Mottet, & Perrey, 2009) as it has recently been reported that even exercise at moderate intensity with its underlying fatigue can have detrimental effects on accuracy (McMorris, Sproule, Turner, & Hale, 2011); (2) The efforts produced with the arms and hands during the HIT on SPT could have caused interference during the consolidation process of the memory trace. Although it is known that the subsequent task should involve learning in order to induce interference, which should not have been the case here (Lundbye-Jensen et al., 2011); (3) RET1 was conducted too soon after the learning phase (i.e., only 30 min). It has been shown that "performing a retention test too early after encoding while the memory trace is still undergoing consolidation could limit exercise-induced memory gains" (Roig et al., 2013, p. 1662); (4) High activations (i.e., moderate to intense exercise) closely following encoding of the memory trace could have inhibited the short-term recall of the AT, but the performed exercise should have facilitated retrieval of information at assessments scheduled more than 30 min after exercise (Labban & Etnier, 2011). This being said, improvements shown by IG from RET1 to RET2 are explained by point four above and are a better reflection of exercise-induced long-term retention of the learned skill and consequently learning than the short-term immediate performance in RET1. However, because no significant time*interaction effect was proven with the ANOVA, it has to be kept in mind that these results are only trends and tendencies towards a positive outcome.

When it comes to the potential benefits of long-term cardiovascular intervention, there was a positive effect on the participants' endurance capacity. At the time of the pre-test session, there was no significant difference in fitness level between groups. In contrast, IG showed improvements in running speed during the post-test assessment rendering the difference between the groups significant at the second time point. Importantly, the four week training programme elevated the participants' fitness level despite relatively short training durations. This initial gain in endurance capacity was the milestone towards the expected further enhancement in motor memory consolidation caused by the acute bout of exercise.

Literature (Roig et al., 2013) implies that long-term cardiovascular exercise has the ability to maintain the underpinning mechanisms of memory processing and therefore supports the effects of acute bouts of exercise. Consequently, we originally speculated that the difference between groups in the long-term retention of the AT would grow larger thanks to the support of the regular exercise performed during four weeks. Unfortunately, despite the significant progress in endurance, this cannot be proven with the results of this study. It appears that neither group learned the second AT (AT2 after the four week training intervention) as the performance remained similar from start to finish (Fig. 20A). Due to the absence of learning, it makes no sense to discuss consolidation, short and long-term retention of the task or the potential impact of the higher fitness levels achieved by the IG. However, we will propose some potential explanations for this situation.

Firstly, we presume that the difficulty in the proposed AT was mainly the capacity to use the highly sensitive lever. Indeed, minimal pressure sufficed to provoke an immediate change in the force signal shown on the screen. Once participants adapted to this and learned how to use the lever, following the reference curve was no longer a challenge. In the pre-test sessions, participants learned generalities (i.e., how much pressure needed to be applied on the lever to influence their force signal as desired) that surpassed learning to follow the curve shown on the screen. As a result, the memory trace for the adaptation to the sensitivity of the lever was encoded and consolidated following the very first acquisition phase. This explanation is supported by the fact that neither group learned the AT2 although a new reference curve was proposed specifically in order to induce new learning.

Secondly, the mediocre performance and perhaps equally the absence of learning in the acquisition phase could conceivably be due to poor attention caused by the lack of interest in practising an AT for a second time. All participants seemed focused and concentrated while performing the AT2, however they might not have been fully motivated nor interested in achieving the specified goal of the task (i.e., tracking the reference curve as precisely as possible) but simply went through the task. Other factors such as sleep deprivation (Alkadhi, Zagaar, Alhaider, Salim, & Aleisa, 2013) and a high fat diet (Vaynman & Gomez-Pinilla, 2006) for example, also influence motor learning and could therefore have had a negative impact on results. However, this is only a speculation as the participants' sleeping and eating habits were not controlled. Consequently, it is supposed that the absence of learning in the post-tests can most probably be explained by the fact that the ability to produce very light forces was consolidated from the pre-tests.

Finally, there was a significant difference in performance among groups in the post-test AT learning phase. Although neither group learned, CG's overall performance was significantly better than that of IG (Fig, 20C). It is unclear why this difference appears. Here, we could suppose that the participants of the IG had invested a lot of time and energy into the study by training on the SPT three times a week during one month and possibly had decreased motivation or interest in performing the task. Nonetheless, the potential of the long-term programme is not questioned and further research combining both acute and long-term aerobic exercise needs to be conducted.

Although comparisons with other studies are difficult due to the poor results achieved in this study, the experiment that was conducted seems to have potential as its design resembles previous studies that achieved positive relationships between physical exercise and cognition. To date, most studies have focused on the impact of various forms of cardiovascular exercise on explicit memory (e.g., verbal memory, special memory and visual memory). In their work evaluating the effects of a brief bout of exercise on executive function, short-term memory and long-term memory, Coles & Tomporowski (2008) had participants perform various tests before and after 40 min of moderate aerobic exercise on the cycle ergometer. They found that exercise did not enhance short-term memory but facilitated the consolidation of information into long-term memory. These conclusions resemble those that we were expecting to obtain in my research. Another study (Labban & Etnier, 2011) tested the effects of acute bout exercise on long-term memory while focusing on the importance of the timing of the activity in relation to the memory task (i.e., a paragraph recall task). In addition to a control group who only performed the memory task, two other groups exercised during 30 min on a cycle ergometer either before or after exposure to the memory task. All three groups performed the recall test 30 min after exposure. Results showed that acute exercise positively impacts recall with an important influence being the timing of exercise as only the group who was active before the cognitive task showed significant differences in recall compared to the control group. Furthermore, with their research, Roig et al. (2012) were the first to focus on motor memory and skill learning. The new evidence that arose from their study shed light on the effects of an acute intervention on memory consolidation, by demonstrating that the capacity of this type of exercise regime to improve memory highly depends on the timing of the exercise bout in relation to the exposure to a task. Their results contrasted with those of Labban & Etnier (2011) as they concluded that exercise after exposure rather than before exposure has the largest effects on long-term memory. Additionally, they illustrated the importance of performing a delayed retention test (i.e., 24 hours and 7 days) to effectively show the full potential of the exercise-induced improvements in long-term memory, which had rarely been implemented in previous studies. Although we hoped to achieve the same results as did Roig et al. in 2012, as discussed earlier in this chapter, many elements biased the results and consequently led to the unexpected outcomes.

5. Conclusions

It is difficult to draw any definitive conclusions from this study. There is a trend towards obtaining results that compare favourably to those achieved by Roig et al. in 2012, however our findings are not as substantial as their results (i.e., that the positive effects of acute exercise on motor memory are maximised when exercise is performed immediately after practice during the early stages of memory consolidation). The present data shows the limitations of our study.

Firstly, the organisation of the study was not ideal. By combining tests for two simultaneous studies, methodological bias was induced causing the main set of data (i.e., performance at RET3) to be inadequate. Secondly, intensity during the HIT and the training sessions was not set to a specific level. Literature supports that exercise is facilitative when submaximal (moderate and individualised intensity) protocols are sufficient to elicit physiological changes without leading to fatigue (Brisswalter, Collardeau, & Rene, 2002). Although the intensity of the acute bout of exercise does not seem to affect long-term retention of skills (Roig et al., 2013), there could have been a difference within the participants' workload during the acute bout of exercise and the long-term intervention. This could have had a potentially negative influence on the benefits of exercise on the long-term retention of the AT. Unfortunately, due to the specific characteristics of the SPT, setting precise levels of intensity during trainings was impossible. However, the use of four additional objective or subjective methods could have given a better understanding of the participants workload during physical exercise: (1) Analysis of the heart rate data that was recorded during all physical exercises; (2) Assessment of fitness level (with blood lactate concentration) before beginning the study (3) Assessment of blood lactate concentration during graded cardiovascular exercise test as well as after HIT and all training sessions; (4) Evaluation of fatigue with a Borg scale recording perceived level of exertion at the end of exercise.

To conclude, the study Roig et al. conducted in 2012 was the first experiment to investigate the impact of acute exercise on skill learning and motor memory. This added new evidence to the existing body of literature but further experiments need to be conducted to determine the extent of their results. In light of this, the present work used a similar study design and AT to determine whether the results would equally be achieved with a different mode of exercise (i.e., SPT instead of cycling). Although, it is known that cycling is the most effective mode of exercise to improve long-term memory (Roig et al., 2013), there is no particular reason why using the SPT could not achieve similar results. This was partially the case. However, due to all the challenges we came across during the implementation of the study and analysis of the results, few positive conclusions can concretely be drawn. Consequently, further research with corrected methodologies, an improved AT and a better monitoring of exercise intensity could lead to a more positive outcome.

In addition to the positive effects of exercise that have been discussed in this thesis, it is known that stress, nutrition and sleep all have an influence on learning motor skills. Further potential studies combining the effects of exercise whilst taking these factors into consideration would widen the knowledge in this field.

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Declaration of Academic integrity

"I, the undersigned, hereby declare that this thesis and the work presented in it is entirely my own. Where I have consulted the work of others this is always clearly stated.”

Place, date: Fribourg, 12 February 2014 Signature:

Copyright

"I, the undersigned, recognise that the present work is an integrated part of the training programme in Movement and Sport Sciences of the University of Fribourg. I am therefore committed to fully handing over the copyright – including publication rights and other rights linked to commercial or non-commercial purposes – to the University of Fribourg.
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Appendices

Appendix A: Recruitment Email or Flyer

(French version)

Nouvel appareil de fitness : que peut faire le SensoProTrainer® ?

Nous sommes deux étudiantes en Sciences du Sport et de la Motricité de l'Université de Fribourg. Dans le cadre de notre travail de Master, nous allons mener une étude dans le but de déterminer les possibilités et l'efficacité des entraînements sur le SensoProTrainer®. Deux thèmes différents seront abordés ; le premier regroupe l'endurance et l'équilibre alors que le second s'intéresse à l'apprentissage moteur. Pour cela, nous avons besoin de sujets intéressés à s'entraîner 3 fois par semaine durant un mois sur le SensoProTrainer®.

Le SensoProTrainer® est un appareil de fitness multifonctionnel et polyvalent permettant d'entraîner simultanément l'endurance, la force et la coordination (cf. image).


Source : http://www.sensoprotrainer.ch/produkt

L'étude débutera avec les pré-tests (tests endurance, équilibre et tâche motrice). Les entraînements débuteront la semaine suivante et dureront un maximum de 30 minutes chacun. Ils incluront des exercices d'endurance et d'équilibre. Durant cette période d'un mois, les sujets du groupe contrôle ne s'entraînent pas sur le SensoProTrainer® mais pratiquent simplement leurs activités quotidiennes habituelles. L'étude se terminera par des post-tests pour les deux groupes (intervention et contrôle).

URGENT !!!! Nous avons besoin de votre aide : nous cherchons des femmes et hommes âgés de 18-30 ans qui ne sont pas très actifs au quotidien (moins de 2h30 d'activité sportive par semaine). Si vous êtes intéressés à participer à cette étude (choix entre groupe contrôle ou groupe intervention), contactez nous jusqu'au vendredi 20 septembre 2013 à 20h !

Vous recevrez une rétribution financière pour votre participation (groupe intervention : 100CHF et groupe contrôle : 25CHF) !

Pour de plus amples informations, nous restons évidemment à votre disposition.

Meilleures salutations,

Sarah Kershaw (Français-Anglais) sarah.kershaw@unifr.ch
et
Melanie Messerli (Allemand- Anglais) melanie.messerli@unifr.ch

Appendix B: Information for participants

(French version)

Etude SensoProTrainer®

Information aux participants de l'étude

Vous êtes invités à prendre part à une étude de recherche de l'unité de sport de l'Université de Fribourg. Cette étude s'intéresse aux effets que pourrait avoir un entraînement sur le SensoProTrainer® (SPT) sur l'endurance, l'équilibre et l'apprentissage moteur.

But de l'étude

Le SPT est un nouvel appareil de fitness qui vient juste d'être mis sur le marché. Jusqu'à présent, aucune étude scientifique recherchant les possibles effets d'un entraînement sur cette machine n'a encore été menée. Le but de cette étude est le suivant : Déterminer si un entraînement de quatre semaines (trois séances par semaine) sur le SPT peut améliorer de manière significative les capacités d'endurance et d'équilibre. De plus, il s'agit d'observer si une séance d'effort physique intense pratiquée après l'apprentissage d'une tâche motrice a un effet sur la mémoire motrice.

Conditions de participation à l'étude

Si vous êtes en bonne santé, âgé entre 18 et 30 ans, peu actifs au quotidien (≤ 2h30min de sport par semaine) et que vous ne remplissez pas l'un des critères d'exclusion suivants, vous pouvez participer à cette étude.

Critères d'exclusion:

- Les personnes souffrant de maladies cardiaques
- Les personnes avec des blessures orthopédiques sévères
- Les personnes avec des problèmes au niveau neuronal

Vous êtes libres de décider de participer ou non

C’est vous qui décidez si vous participez ou non à l’étude. Si vous décidez de participer, vous signerez un formulaire de consentement. Même après avoir signé ce formulaire de consentement, vous êtes libre de vous retirer de l’étude à n’importe quel moment sans donner de raison. La décision de vous retirer de l’étude ou de ne pas y participer n’a aucune conséquence sur vos études (si vous êtes étudiant) ou sur votre engagement à l’Université (si vous êtes employé).

Si vous vous décidez à participer à cette étude après la lecture des informations des participants et la résolution des questions en suspens, la procédure expérimentale et d’entraînement vous sera également expliquée. Il est important de savoir que vous pouvez abandonner l'enquête à tout moment sans donner de raison et donc interrompre votre participation à l'étude.

Procédure de l’étude

L’idée de cette étude est de déterminer l’effet d’un entraînement sur le SPT sur l’endurance, l’équilibre et l’apprentissage moteur.

Procédure de testing et d‘entraînement:

Avant la signature du formulaire de consentement et le début l’étude, vous êtes évidemment cordialement invités à poser les éventuelles questions résiduelles. Après la signature du document, les tests peuvent débuter.

Lors du premier jour de pré-tests, votre présence est nécessaire durant 1h30 environ. Pour débuter, vous ferez les tests d’équilibre :

- Stabilometer
- Posturomed: avec et sans perturbation de l‘équilibre

Puis, vous passerez à l’apprentissage de la tâche motrice, suivi par l’exercice physique intense sur le SPT (env. 20min). La consolidation de la mémoire sera mesurée grâce à trois tests de rétention (1h, 24h et 7 jours après l’entraînement de la tâche motrice).

Le second jour, vous passerez un test d'effort maximal sur le tapis roulant qui durera jusqu'à épuisement (max 20min). Les paliers durent une minute et la vitesse initiale est fixée à 5.4 km/h. La vitesse est augmentée de 0.6 km/h à chaque nouveau palier. Le test est arrêté lorsque le sujet n'est plus capable de courir à la vitesse donnée. La fréquence cardiaque est notée au repos, puis à la fin de chaque palier. Les valeurs de fréquence cardiaque sont également inscrites immédiatement après l'arrêt du test, ainsi qu'après 1 min et 2 min de récupération. La vitesse maximale atteinte est retenue.

Contenus de l'entraînement :

Le programmeme d'entraînement de quatre semaines (3 séances par semaine) est composé d'une combinaison d'exercices d'endurance et d'équilibre. L'entraînement est durci chaque semaine.

Avantages personnels:

Suite à l'entraînement, vous devriez avoir une meilleure capacité d'endurance et d'équilibre ainsi qu'une capacité d'apprentissage moteur de niveau supérieur.

Méthodes de mesure

Les différentes techniques de mesure sont brièvement présentées ci-dessous.

Test d'effort maximal

Lors du test d'effort maximal, la fréquence cardiaque est mesurée grâce un a cardiofréquencemètre (Polar, Finlande). Les données recueillies (fréquence cardiaque et vitesse maximale) permettent ensuite de tirer des conclusions sur les capacités d'endurance. Le test est effectué sur un tapis roulant et la vitesse est augmentée à chaque palier. Le test est arrêté à l'épuisement du sujet.

Stabilometer

Le Stabilometer est une plateforme mobile qui peut basculer des deux côtés de l'axe central. Le but de ce test est de se tenir sur la plateforme tout en la maintenant le plus stable possible durant 30s. Le Stabilometer mesure l'oscillation du corps.

Posturomed^{TM}

Le Posturomed^{TM} est une plateforme mobile reliée à des ressorts à ses quatre coins. Ceci permet de déterminer la stabilité posturale (sur une jambe) dans le plan transversal. Diverses tâches avec (10s par pied dans trois positions) et sans perturbation (20s par pied) seront testées. Chaque condition est mesurée à trois reprises. Le Posturomed^{TM} permet de déterminer l'oscillation du corps.

Accuracy test

Pour l'évaluation de la capacité d'apprentissage moteur, une tâche motrice doit être apprise. Le but de cette tâche est d'appuyer sur un levier avec l'index afin de suivre au plus près une courbe de base montrée sur un écran d'ordinateur. Cette tâche est effectuée 6 x 2min30 lors de la période d'apprentissage, puis elle sera répétée 2 x 2min30 lors de chaque test de rétention. L'ordinateur évalue la distance d'erreur entre la courbe montrée à l'écran et la courbe dessinée par l'appui sur le levier.

Confidentialité

Toutes les données de l'enregistrement et de l'analyse seront traitées de manière anonyme. L'information personnelle que vous nous donnez et qui vous identifie sera archivée de manière sûre et ne sera pas disponible librement. Cette information sera toutefois disponible aux chercheurs directement impliqués dans l'étude. Vous avez le droit de voir l'information vous concernant et de corriger toute erreur.

Qu'en est-il des résultats de l'étude ?

Les résultats généraux de l'étude seront publiés dans la littérature scientifique. Vos données individuelles ne pourront pas être identifiées. Si vous le désirez, nous vous fournirons volontiers une copie de la publication.

Rétribution financière

Vous serez défrayés à l'issue de l'enquête. Si vous mettez fin à votre participation à l'étude, vous serez défrayé en fonction de votre temps investi. Nous vous rembourserons le montant approprié du temps effectué.

Appendix C: Consent form

(French version)

Unité de Sciences du Mouvement et du Sport - Université de Fribourg

Consentement pour l'étude « **Nouvelle appareil de fitness : SensoProTrainer®** »

Je, soussigné, certifie :

- Avoir lu, compris et accepté l'information contenue dans la « Note d'information aux participants de l'étude ».
- Je confirme que les critères d'exclusion mentionnés dans la «Note d'information aux participants de l'étude » ne me concernent pas.
- Que j'ai pu poser toutes les questions souhaitées et que j'ai reçu des réponses satisfaisantes.
- Etre informé que je peux me retirer à tout moment de l'étude et sans préjudice. Dans ce cas, ma rétribution financière sera calculée en proportion de ma participation à l'étude.
- Etre informé que toutes les données personnelles, résultats obtenus à mon sujet et ma participation à l'étude sont confidentiels et ne seront disponibles qu'aux chercheurs directement impliqués dans cette étude.
- Etre informé que les résultats obtenus lors de l'étude seront publiés de manière anonyme, et sous une forme qui ne peut pas m'identifier, dans une ou plusieurs publications scientifiques. J'y ai donné mon accord.
- Consentir à participer volontairement à l'étude susmentionnée comme sujet.

Sujet de l'étude

Nom: Prénom:

Signature:

Personne ayant conduit l'entretien de consentement

Je confirme avoir personnellement expliqué au sujet désigné ci-dessus la nature, le but, la durée ainsi que les effets et risques prévisibles de l'étude.

Nom: Prénom:

Signature:

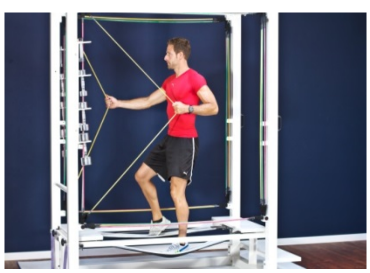
Appendix D: HIT on the SensoProTrainer®

Pre-Tests HIT

Total duration: 12 min

Duration	What ?
2 min : 2 x 30s-30s	**Warm Up :** Bouncing – Jogging (no tubes)
3 min : 3 x 15s-45s	**Interval Training :** Sprint 15s – 45s Exercise with tubes (CrossTraining, Wings, CrossTraining)
2 min:	**Rest:** Bouncing
3 min : **3 x 15-45**	**Interval Training :** Sprint 15s – 45s Exercise with tubes (Wings, CrossTraining, Wings)
2 min	**Rest:** Bouncing

Description of exercises with tubes

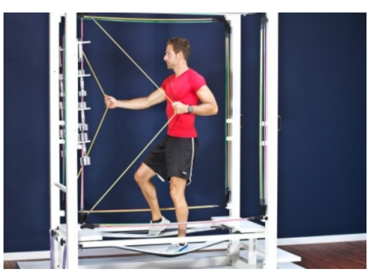
CrossTraining	**Wings**
	

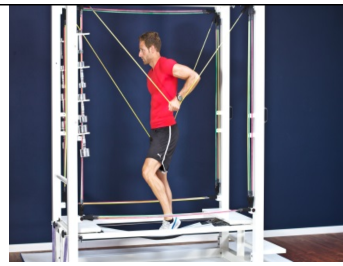
Post-Tests HIT

Total duration: 12min

Duration	What ?
1min	**Warm Up :** Jogging
4min : 4 x 15s-45s	**Interval Training :** Sprint 15s – 45s Exercise with tubes (**Cross-Training, Boxing, Rombo, Dip**)
2min	**Active recovery:** Jogging
4min : 4 x 15s-45s	**Interval Training :** Sprint 15s – 45s Exercise with tubes (**Wings, Boxing, Rombo, Dip**)
1min	**Active recovery:** Jogging

Description of exercises with tubes

CrossTraining	**Wings**	**Boxing**
		
Rombo	**Dip**	

Appendix E: Training sessions of the four week intervention programme

Week 1: 02-08.10.13

Name: .... **Transmitter nr: ....**

Date Training session 1: .... **Time: ....**

Date Training session 2: .... **Time: ....**

Date Training session 3: .... **Time: ....**

Remarks/Problems:

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	Exercise	Description	Number of repetitions	Exercise duration	Light Jogging duration	Level of difficulty
Warm up	*Bouncing* 2x30s Total duration : 2 min	Entire foot on band 	2	30 sec	30 sec	I. Hands on bars II. Hands briefly touch bars III. No help IV. Eyes closed ------------------------------ 1. 2. 3.

	Exercise	Description	Number of repetitions	Exercise duration	Rest duration	Level of difficulty
Balance training (9 minutes)	*One leg balance* 2x30 sec (per leg) **Total duration : 2 min**	Entire foot on band 	2 per leg (alternate right/left)	30 sec	Change leg	I. Holding all upper tubes II. Holding one upper tube III. No help IV. Hands on hips -------------------- 1. 2. 3.
	Surfing 2x30 sec (per leg) **Total duration : 2 min**	Stabilize yourself on band 	2 per leg (alternate right/left)	30 sec	Change leg	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed -------------------- 1. 2. 3.
	Lunges 2x30 sec (per leg) **Total duration : 2 min**	Both feet on band 	2 per leg (alternate right/left)	30 sec	Change leg	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed -------------------- 1. 2. 3.
	Free Swingboard 3x30 sec **Total duration : 3 min**	Stabilize Swingboard (with "friends") 	3	30 sec	30 sec	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed -------------------- 1. 2. 3.

	Exercise	Description	Exercise duration	Sprint duration	Jogging duration	Level of difficulty
Cardio training (12 minutes)	*Cross Training* **Total duration : 3 min**	Use tube in front of you 	2 min	15 sec	45 sec	Choose tube allowing you to do the entire exercise without having to change! -------------------- 1. Y G R 2. Y G R 3. Y G R
	Wings **Total duration : 3 min**	Use tube above you 	2 min	15 sec	45 sec	Choose tube allowing you to do the entire exercise without having to change! -------------------- 1. Y G R 2. Y G R 3. Y G R
	Boxing **Total duration : 3 min**	Use tube behind you 	2 min	15 sec	45 sec	Choose tube allowing you to do the entire exercise without having to change! -------------------- 1. Y G R 2. Y G R 3. Y G R
	Rombo **Total duration : 3 min**	Use tube in front of you 	2 min	15 sec	45 sec	Choose tube allowing you to do the entire exercise without having to change! -------------------- 1. Y G R 2. Y G R 3. Y G R

Week 2: 07-13.10.13

Name: .... **Transmitter nr: ....**

Date Training session 1: .... **Time:** ....

Date Training session 2: .... **Time:** ....

Date Training session 3: .... **Time:** ....

Remarks/Problems:

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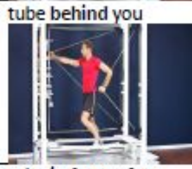
	Exercise	Description	Number of repetitions	Exercise Duration	Light Jogging duration	Level of difficulty
Warm up	*Bouncing* 2x30s Total duration : 2 min	Entire foot on band 	2	30 sec	30 sec	I. Hands on bars II. Hands briefly touch bars III. No help IV. Eyes closed ------------------------------ 1. 2. 3.

	Exercise	Description	Number of repetitions	Exercise duration	Rest duration	Level of difficulty
Balance training (9 minutes)	*One leg balance* 2x30 sec (per leg) Total duration : 2 min	Lightly bounce 	2 per leg (alternate right/left)	30 sec	Change leg	I. Holding all upper tubes II. Holding one upper tube III. No help IV. Hands on hips ------------------------------ 1. 2. 3.
	Surfing 2x30 sec (per leg) Total duration : 2 min	On tiptoes 	2 per leg (alternate right/left)	30 sec	Change leg	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed ------------------------------ 1. 2. 3.
	Lunges 2x30 sec (per leg) Total duration : 2 min	Front foot on Slackline 	2 per leg (alternate right/left)	30 sec	Change leg	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed ------------------------------ 1. 2. 3.
	Free Swingboard 3x30 sec Total duration : 3 min	Stabilize Swingboard (without "friends") 	3	30 sec	30 sec	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed ------------------------------ 1. 2. 3.

	Exercise	Description	Exercise duration	Sprint duration	Jogging duration	Level of difficulty
Cardio training (12 minutes)	*Cross Training* Total duration : 3 min	Use tube in front of you 	2 min	20 sec	40 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R
	Wings Total duration : 3 min	Use tube above you 	2 min	20 sec	40 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R
	Boxing Total duration : 3 min	Use tube behind you 	2 min	20 sec	40 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R
	Rombo Total duration : 3 min	Use tube in front of you 	2 min	20 sec	40 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R

Week 3: 14-20.10.13

Name: .... Transmitter nr: ....

Date Training session 1: .... Time: ....

Date Training session 2: .... Time: ....

Date Training session 3: .... Time: ....

Remarks/Problems:

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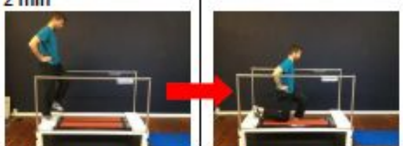
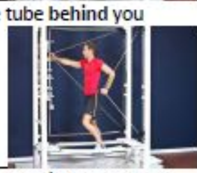
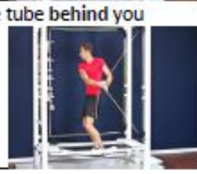
	Exercise	Description	Number of repetitions	Exercise duration	Light Jogging duration	Level of difficulty
Warm up	*Bouncing* 2x30s Total duration : 2 min	On tiptoes 	2	30 sec	30 sec	I. Hands on bars II. Hands briefly touch bars III. No help IV. Eyes closed ------------------------------ 1. 2. 3.

	Exercise	Description	Number of repetitions	Exercise duration	Rest duration	Level of difficulty
Balance training	*One leg balance* 2x30 sec (per leg) **Total duration : 2 min**	Squats 	2 per leg (alternate right/left)	30 sec	Change leg	I. Holding all upper tubes II. Holding one upper tube III. No help IV. Hands on hips ------------------------------ 1. 2. 3.
	Surfing 2x30 sec (per leg) **Total duration : 2 min**	Front foot on Slackline 	2 per leg (alternate right/left)	30 sec	Change leg	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed ------------------------------ 1. 2. 3.
	Deep Dynamic Lunges 2x30 sec (per leg) **Total duration : 2 min** 	Stabilize position + return dynamically to the board	2 per leg (alternate right/left)	30 sec	Change leg	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed ------------------------------ 1. 2. 3.
	Free Swingboard 3x30 sec **Total duration : 3 min**	Squats (with "friends") 	3	30 sec	30 sec	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed ------------------------------ 1. 2. 3.

	Exercise	Description	Jogging duration	Sprint duration	Rest duration	Level of difficulty
Cardio training (18 min)	*Cross Training* **Total duration : 3 min**	Use tube in front of you 	2 min	15 sec	45 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R
	Wings **Total duration : 3 min**	Use tube above you 	2 min	15 sec	45 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R
	Boxing **Total duration : 3 min**	Use tube behind you 	2 min	15 sec	45 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R
	Rombo **Total duration : 3 min**	Use tube in front of you 	2 min	15 sec	45 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R

	Dip **Total duration : 3 min**	Use tube above you 	2 min	15 sec	45 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R
	Cross Chop **Total duration : 3 min**	Use tube behind you 	2 min (1 min per arm)	15 sec	45 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R

Week 4: 21-27.10.13

Name: .... Transmitter nr: ....

Date Training session 1: .... **Time:** ....

Date Training session 2: .... **Time:** ....

Date Training session 3: .... **Time:** ....

Remarks/Problems:

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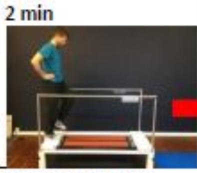
	Exercise	Description	Number of repetitions	Exercise duration	Light Jogging duration	Level of difficulty
Warm up	*Bouncing* 2x30s Total duration : 2 min	On tiptoes 	2	30 sec	30 sec	I. Hands on bars II. Hands briefly touch bars III. No help IV. Eyes closed ------------------------------ 1. 2. 3.

	Exercise	Description	Number of repetitions	Exercise Duration	Rest duration	Level of difficulty
Balance training	*One leg balance* 2x30 sec (per leg) **Total duration : 2 min**	Balance yourself on the Slackline 	2 per leg (alternate right/left)	30 sec	Change leg	I. Holding all upper tubes II. Holding one upper tube III. No help IV. Hands on hips ------------------------------ 1. 2. 3.
	Surfing 2x30 sec (per leg) **Total duration : 2 min**	Both feet on the Slackline 	2 per leg (alternate right/left)	30 sec	Change leg	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed ------------------------------ 1. 2. 3.
	Deep Dynamic Lunges 2x30 sec (per leg) **Total duration : 2 min** 	Stabilize position + push back dynamically to board without putting your foot down 	2 per leg (alternate right/left)	30 sec	Change leg	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed ------------------------------ 1. 2. 3.
	Free Swingboard 3x30 sec **Total duration : 3 min**	Squats (without "friends") 	3	30 sec	30 sec	I. Hands on bars II. No help III. Hands in front of you IV. Eyes closed ------------------------------ 1. 2. 3.

	Exercise	Description	Exercise duration	Sprint duration	Jogging duration	Level of difficulty
Cardio training (18 minutes)	*Cross Training* **Total duration : 3 min**	Use tube in front of you 	2 min	20 sec	40 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R
	Wings **Total duration : 3 min**	Use tube above you 	2 min	20 sec	40 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R
	Boxing **Total duration : 3 min**	Use tube behind you 	2 min	20 sec	40 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R
	Rombo **Total duration : 3 min**	Use tube in front of you 	2 min	20 sec	40 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------ 1. Y G R 2. Y G R 3. Y G R

	Dip **Total duration : 3 min**	Use tube above you 	2 min	20 sec	40 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------------ 1. Y G R 2. Y G R 3. Y G R
	Cross Chop **Total duration : 3 min**	Use tube behind you 	2 min (1 min per arm)	20 sec	40 sec	Choose tube allowing you to do the entire exercise without having to change! ------------------------------------ 1. Y G R 2. Y G R 3. Y G R