University of Lille (SHS)
SCALab Laboratory UMR CNRS 9193 – AVA Team

PROFILING INDIVIDUALS FOR PLEASURABLE PHYSICAL EXERCISE: THE NEUROPSYCHOLOGY OF TOLERANCE TO EFFORT

Thesis defended on November 27th 2017

Written by:

Mauraine CARLIER

Under the supervision of:

Pr Yvonne DELEVOYE-TURRELL

Jury panel:
Pr Yvonne DELEVOYE-TURRELL, University of Lille (SHS) (Directrice)
Pr Pascale PIOLINO, University of Paris Descartes (Rapporteur)
Pr Michel AUDIFFREN, University of Poitiers (Rapporteur)
Pr Muriel GARCIN, University of Lille (Examinatrice)
Pr Caterina PESCE, University of Roma (Examinatrice)
Pr Gershon TENENBAUM, Florida State University (Examinateur)

TABLE OF CONTENTS

Abstract

Affective responses to physical exercise have been reported as predictors of the degree of engagement a person is ready to set in regular practice (Mohiyeddini, Pauli, & Bauer, 2009). According to the dual mode theory, the individuals' differences occurring during the exercise are due to the interplay between one's physical abilities and one's psychological characteristics (Ekkekakis, 2003) with some experiencing positively the session while others do not (Van Landuyt, Ekkekakis, Hall, & Petruzzello, 2000). Hence, my thesis work targeted the better understanding of the effect of one of the psychological characteristics, the Tolerance to effort, on one's affective responses during moderate physical exercise. Furthermore, I tried to reveal that a neuropsychological definition of the Tolerance to effort can be possible, even required for prescribing exercise program. Tolerance is defined as a trait that influences one's ability to continue exercising at an imposed level of intensity even if the activity becomes uncomfortable or unpleasant (Ekkekakis, Hall, & Petruzzello, 2005). To date, my work has revealed that the concept of Tolerance seems to be a valid concept in a French-speaking European sample (Study I). Interestingly, the results were revealed whatever the individuals' self-reported weekly physical practice. My work also shows that the way one experiences a physical exercise depends on one's tolerance level (Studies II and IV). Furthermore, the more individuals were tolerant to effort, the more they were able to produce intense physical exercise (Studies III and IV). Interestingly, results revealed that one's tolerance level seems to be associated with one's efficiency of cognitive functioning. More specifically, the more individuals possess efficient executive functions, the more they possess high level of Tolerance to effort (Study III). Finally, the positive effect of a musical distracting environment on one's perception of physical exercise difficulty was revealed only in high tolerant individuals (Study IV); suggesting that music may not be adapted to all. To conclude, through the conduction of a psychometric assessment of the French-speaking version (Study I), a dual task paradigm (Study II) and a neuropsychological assessment of individuals cognitive abilities (Study III), my thesis work has revealed that one's tolerance level seems to be a French-speaking valid concept predicting the positive or negative affective response to physical exercise either in silence or in music (Studies II and IV) and defining one's tolerance to effort from a cognitive standpoint.

Key words: Tolerance to effort; Neuropsychology; Cognition; Executive Functions; Affective states; Self-regulation; Self-paced protocol

Remerciements

Pouvoir soutenir sa thèse de doctorat ne peut être possible qu'avec le soutien de son entourage. Ainsi, vous trouverez dans cette partie le témoignage le plus humble que je puisse me permettre de donner à toutes ces personnes qui m'ont accompagnée.

Madame la Professeure Piolino, Monsieur le Professeur Audiffren, bénéficier de votre expertise comme rapporteurs de mon travail de thèse fût un véritable honneur. Vos remarques m'ont permis d'aller plus loin et pour cela je vous remercie.

Madame la Professeure Garcin, Professor Tenenbaum, Professor Pesce, benefiting from your presence at my thesis defense was a great honor. Thank you for having taken the time to share your expertise with me and to enable me to improve my thoughts. Professor Tenenbaum, Professor Pesce, more than to others, thank you for having travelled for a long time up to here

Madame la Professeure Delevoye-Turrell, les mots ne seront retranscrire la reconnaissance que je vous porte. Réaliser une thèse auprès de vous fût une véritable expérience tant professionnelle qu'humaine. Vous m'avez permis de repousser mes limites chaque jour, d'avoir foi en ce travail et surtout en moi. Ainsi, pour votre temps, pour votre abnégation et pour le coeur que vous avez mis à cette expérience de vie, je vous dis merci.

Professor Ekkekakis, you remind me that the willingness to improve the health of people is a part of a peaceful life. You also help me to understand that the work conducted in this thesis could be a way to attain such a goal. For this, and for the wellbeing you enabled me to attain, I am deeply grateful to you.

Monsieur le Professeur Coello, je souhaite vous remercier pour votre accompagnement, pour vos encouragements et pour nos discussions théoriques. Je vous remercie également pour avoir été le premier à me donner la chance de prouver mes qualités en tant que jeune chercheuse. Vous avez été un tuteur de premier ordre et je suis persuadée que vos encouragements permettront à d'autres d'avancer et de se surpasser. A vous, je dis merci.

Messieurs, Mesdames, les membres du laboratoire SCALab, Messieurs, Mesdames les membres de l'Equipex, travailler au sein de vos équipes, vous côtoyer chaque jour et pouvoir partager avec vous fût un réel plaisir, un pur moment de bonheur et de partages tant professionnels qu'humains. Pour tout cela, je vous remercie.

Messieurs, Mesdames, les doctorants du laboratoire SCALab, continuez à vibrer comme vous le faites, continuer à faire reculer les limites dans la joie et la bonne humeur parce que c'est bien cela qui vous caractérise. Madame Karinne, Messieurs Yannick et François, vous

m’avez apporté cet horizon et cet aiguillage chaque jour et pour ça je vous dis un immense merci.

Emilie Constant, à toi particulièrement, pour ta joie, ta bonne humeur et surtout ton aide, merci.

Messieurs, Mesdames, étudiant(e)s qui avaient travaillé avec moi, qui vous êtes investis dans ces aventures sans que la fatigue ni la perte de motivation ne vous gagnent, à vous, merci.

Messieurs, Mesdames, participants de toutes ces études, ces résultats vous reviennent également. A vous merci.

Madame Delebarre, Monsieur Leroy, médecins de l’université de Lille et partenaires indéfectibles de ces années de thèse, Alexandre et membres du réseau TC/AVC de la région Hauts-de-France, Messieurs les créateurs de Running Care, Geoffrey, votre intérêt médical pour cette thèse a été un vrai souffle, alors à vous, autant et parfois à plus qu’à d’autres, un immense merci.

Mesdames les mousquetaires, Monsieur Alex, Madame Laetitia, Monsieur Romain, Madame Maud, Madame Amandine, Mesdames les paillettes, je ne peux rien vous dire d’autre que merci. Chaque instant fût une merveille de bonheur et chaque difficulté ne fût que la preuve de la profonde amitié qui me lie à vous. A vous, merci.

Nathalie, pour tout, et pour bien plus encore, merci.

A toi, dont l’implication fût brève mais son rôle primordial. A toi, merci.

Enfin, l’atteinte d’un tel objectif ne fût possible qu’avec une force de conviction dont mes parents et ma sœur sont les moteurs et les piliers. Ces êtres qui ont su continuer contre vents et marrées, contre la souffrance et contre des journées bien compliquées. Qui ont su créer un monde de paix et de respect dont chaque minute est dotée d’un caractère divin. Que la fierté de ce travail accompli puisse leur revenir à eux, car particulièrement à eux je leur dis merci.

Que ce travail vous soit un plaisir de lecture comme il a été pour moi un pur moment d’écriture et d’épanouissement. Avec tout mon respect et mon dévouement.

Mauraine

Part 1

THEORETICAL INTRODUCTION

Chapter 1:

Regularly exercise, a way to flourish

I. Health definition

"Health is defined as a state of global physical, psychological and social wellbeing and does not consist only in the absence of disease or disability" (World Health Organisation, 1946). This definition was created after the Second World War where people saw and experienced horrible and difficult events both from physical and psychological standpoints. In the historic context of the post-war period and the psychological consequences of this event, clinicians and scientists in the field of psychology were assigned to cure mental illness and enhance wellness of the post-war affected population (Hefferon & Boniwell, 2011). Thanks to scientific funding, 14 disorders can now be cured or considerably relieved (Seligman & Csikszentmihalyi, 2000). However, due to the urgent need to take care of psychologically impaired soldiers, the aim of enhancing the lives of the normal population was set aside (Linley, 2009). Consequently, one’s life in the 21st century does not necessarily reach the health and wellbeing levels psychologists could have hoped during the post war period.

Nowadays, at a psychological level, approximately 450 million individuals suffer from a mental or behavioural disorder (WHO, 2003). More interestingly, among those who are not suffering from referenced diseases or disabilities, there are increasing signs that less than optimal mental wellbeing is common in the general population (e.g., emotional distress, low self-esteem, poor body image, chronic anxiety and stress). These symptoms are now impacting the demands of primary care and social services (Fox, Boutcher, Faulkner, & Biddle, 2000). For example, only 26 % of the individuals who received prescription for antidepressants were being treated for depression and the others were possibly treated for back pain and headaches, anxiety, adjustment disorders, sleep disorders, or fatigue (Ekkekakis, 2013). Furthermore, even if individuals have a greater access to food and advanced medical treatment, compared to the post-war period, people still suffer from many physical diseases (e.g., obesity, cancers, cardiovascular diseases), mostly due to sedentary behaviours (i.e., sitting the most part of the day, using motorized transports) and physically inactivity (i.e., not reaching the recommended minimum physical activity; Katzmarzyk & Lee, 2012; Reimers, Knapp, & Reimers, 2012; Schuna, Johnson, & Tudor-Locke, 2013). In such a context, the question of the 21st century is: ***How may we bring people to flourish and experience a good life with happiness, wellbeing and personal growth?***

II. The importance of flourishing in everyday life

The world flourish originally comes from the Latin word flor (flower) and is synonymous to growth and development (Hefferon, 2013). The concept of flourishing defines « a state of positive mental health; to thrive, to prosper, and to fare well in endeavours free of mental illness, filed with emotional vitality and function positively in private and social realms » (Michalec, Keyes, & Nalkur, 2009). The concept of flourishing has been developed in the field of positive psychology that is concerned with the « scientific study of virtue, meaning, resilience and wellbeing, as well as the evidence based applications to improve the life of individuals and society in the totally of life » (Wong, 2011, p. 72). From this perspective, the absence of mental illness does not imply the presence of mental health (Hefferon, 2013) and the key for moving more into the « flourishing » state could be achieved by reducing the mean number of stress-related symptoms within the normal population (Huppert, 2005) by looking at ***our strengths***

rather than our weaknesses (Hefferon, 2013). More specifically, conducting activities that enhance our strengths would allow us to experience positive emotions, a core feature of the flourishing state (Huppert, 2005; 2009); enabling us to widen our thought process by *creating a «protective reservoir » upon which we can draw from during unpleasant or distressing times* (Hefferon & Boniwell, 2011); leading to explain why flourishing activities are positively correlated with academic achievement, mastery, goal setting, higher levels of control and continued perseverance (Hefferon, 2013) as well as fewer days off work (Keyes, 2002). Conversely, conducting activities with the aim to decrease or suppress our weaknesses would lead to the experience of negative emotions the creation of a negative reservoir biaising the most of our thoughts and leading possibly to psychological diseases, anxiety or depression (Hefferon, 2013). Interestingly, when assessing the environmental conditions enabling individuals to thrive and prosper, the regular practice of a physical exercise is one of them (Mutrie & Faulkner, 2004).

III. Flourishing through physical exercise

In positive psychology, the positive effects of exercising on both mental and physical health is based on the fact that “the body is more than simply another machine, indistinguishable from the artificial objects of the world” *(Gardner, 1993, 235-6).* “It is also the vessel of the individual's sense of self, his most personal feelings and aspiration, as well as that entity to which others respond in a special way because of their uniquely human qualities” *(Gardner, 1993, 235-6).* Thus, sometimes, the best way to fight, change, or influence negative thoughts is not through the same mechanisms, but by taking a more somatic approach (Hefferon, 2013). The key role of the body in the improvement of well-being would also work by enhancing clinical populations’ body awareness by bringing them to « make friends » with their somatic sensations and reconnecting patients to their body (Bradt, Goodill, & Dileo, 2011; Strassel, Cherkin, Steuten, Sherman, &

Vrijhoef, 2011) instead of ignoring it (Hefferon, 2013). As such, in psychotherapy, physical exercise can be used for several issues to improve coping strategies. In particular, to create a sense of self and positive body image; to increase locus of control and to improve self-efficacy (Hefferon, 2013).

Nonetheless, even if exercising regularly enables individuals and communities to prosper thanks to both physical and psychological benefits (Mutrie & Faulkner, 2004), 30 to 60% of the world population do not practice enough physical activity (Hallal et al., 2012). In Europe, 60 % of adults admit not to engage in any physical exercise at all (Eurobarometer, 2010). In the United States, less than 50% of adults is considered physically active (Haskell et al., 2007) and in Canada only 15% of adults follow national guidelines (Colley et al., 2011). Contrary to an active lifestyle, being physically inactive increases the occurrence of metabolic syndromes such as obesity, cardiovascular diseases, insulin resistance and cancers (Oja & Borms, 2004) independently of the traditional risk factors such as smoking, blood pressure, cholesterol, waist circumference, dietary balance (Slattery & Jacobs, 1988) or sedentary behaviours (Reimers et al., 2012). Hence, because of the now demonstrated positive effects of regular exercising and the negative effects of physical inactivity, the physical inactivity is considered as "the biggest public health issue of the 21st century" (Blair, 2009) and a predominant concern in public health (Hall & Fong, 2015). ***The question now is: How to get individuals to engage voluntarily in regular exercise?***

IV. Placing the individuals' characteristics and the pleasantness of a physical exercise at the core of the physical exercise framework

Until now, significant research has been conducted to understand both the individual and the environmental factors responsible for the initiation and the maintenance of exercising health behaviours (Schutzer & Graves, 2004; Trost, Owen, Bauman, Sallis, & Brown, 2002; Wang & Zhang, 2016). Thus, the long-lasting adherence to physical exercise can be explained, to some extent, by the theory of planned behaviour, the social-cognitive theory or the trans-theoretical model (Shumaker, Ockene, & Riekert, 2008). Nonetheless, promoting exercising behaviour is more difficult than promoting other health behaviours such as brushing teeth, eating 5 fruits and vegetables per day, or having safe sex practices (Dishman & Buckworth, 1996). In fact, in comparison to deciding to eat more fruits and vegetables or to brush teeth, engaging in a regular exercise requires to daily negotiating with everyday outcomes and to take time for exercising whatever the environmental changes and constraints (Mullen & Hall, 2015). Thus, even if the experimental interventions are successful, the ecological interventions conducted do not always have the desired effect on individuals' adherence. More specifically, despite increasing intention in participants to become physically more active (Milne, Orbell, & Sheeran, 2002), the non-enough sufficient ecological interventions lead 40 to 65 % of individuals initiating exercise programs are predicted to dropout within 3 to 6 months (Annesi, 2003).

Rationally informing individuals about the benefits of regular practice seems to allow them to be motivated extrinsically to enrol in a sports club or gym (Herring, Sailors, & Bray, 2014). On the other hand, studies suggest that the intrinsic motivation (Teixeira, Carraça, Markland, Silva, & Ryan, 2012) and the pleasure experienced during the session (Jekauc, 2015; Zenko, Ekkekakis, & Ariely, 2016) are particularly important for physical exercise adherence. Such empirical observations were confirmed by the work conducted by Mohiyeddini, Pauli and Bauer (2009). More specifically, authors reported that considering the emotional appraisal of a physical exercise in addition to individuals' intention in a predictive model increases the quality of the prediction of a future practice; suggesting that promoting efficiently the regular physical exercise means considering humans' affective responses in addition to humans' rational mind (Ekkekakis, Parfitt, & Petruzzello, 2011). Nevertheless, we should note that even though the adage "exercise makes people feel better" (Fox, 1999) is spread and "universally accepted" (Morgan, 1981, p.306 - as cited in Ekkekakis, 2013), all individuals are not equal for experiencing positively a given exercise session. More specifically, in a given context, while some experience positively the session, others do not (Backhouse, Ekkekakis, Bidle, Foskett, & Williams, 2007; Van Landuyt et al., 2000). Since the affective states experienced during physical exercise may contribute to the formation of a positive or negative memory trace for exercising, the more the experience is positive, the more the memory trace is positive and the more individuals want to engage (Ekkekakis et al., 2011). Otherwise, the more the experience is negative, the more the memory trace is negative and the more individuals want to drop out. Hence, because affective states would depend on an individuals' physical competences and psychological characteristics, ***understanding the psychological mechanisms underlying the affective responses to physically exercise can be a way forward more efficient promotions of exercising health behaviours*** (Ekkekakis, Thome, Petruzzello, & Hall, 2008; Wienke & Jekauc, 2016).

This thesis work roots within the idea that positive affects and flourishment may emerge during physical exercise. However, such experience would be a function of the match that may exist between individuals' motor control abilities and the motor complexity of the physical exercise. More specifically, the more individuals possess enough cognitive abilities to handle the cognitive challenges occurring during the task, the more they will be able to experience the session as positive. Conversely, the less individuals possess cognitive abilities to handle the cognitive challenges occurring during the task, the less they will be able to experience the session as positive. Hence, in the chapter II, the thesis work defends the idea that performing a physical exercise requires the involvement of cognitive functions to constantly plan, control and regulate the motor behaviour output. In such a case, possessing the required cognitive resources to handle the demands of the task will enable individuals to experience positively the session. However, in a case of a too high discrepancy between the cognitive resources required and individuals' baseline abilities, the performance of a physical exercise will be experienced more negatively. Thirdly, in the framework of embodiment, we will argue that the way one experiences positively or negatively a physical exercise reflects the difficulties one encounters in the self-regulation of one's motor behaviour. Thus, considering one's affective state during the performance of a physical exercise may be a valid tell-tale of one's difficulties. Hence, throughout the third chapter, the essential role of one's affective states *during* physical exercise session will be exposed. Finally, since all individuals do not possess equal cognitive abilities for the control of adaptive motor behaviour or the tolerance of difficulties, the last part of this introductory chapter will concern the possibility to distinguish individuals through the concept of Tolerance to effort.

Chapter 2:

The cognitive window into physical exercise

Physical exercise is a type of motor activity that requires organisation, planning and sequencing of bodily movements performed in the aim to improve and/or maintain one or more components of physical fitness (American College of Sports Medicine, Thompson, Gordon, & Pescatello, 2010). Hence, exercising consists in the task of regularly producing series of coordinated contractions of skeletal muscles that results in a substantial increase in caloric requirements compared to the energy expenditure measured at rest (Caspersen, Powell, & Christenson, 1985). Under such condition, the most usual way to categorise physical exercise is by looking at their energy expenditure (i.e., Metabolic Equivalent of Task – METs; American College of Sports Medicine et al., 2010). More specifically, during the performance of a physical exercise, one's body consume oxygen for producing energy. Thus, the METs correspond to the oxygen consumption at each minute by each kilogramme of an individual's body during motor performance. Low intense physical exercise (e.g., walking slowly around home, playing instrument) is defined as requiring less than 3 METs to be performed, moderate physical exercise is associated to the necessity to expend 3 to 6 METs (e.g., walking at a very brisk pace, dancing, doing badminton) and vigorous physical exercise is defined as requiring an energy expenditure of 6 METs (e.g., walking at a highly brisk pace, running, basketball game).

Physical exercise has also been defined as emanating from the complex interaction of perceptual, cognitive, and metabolic processes (Borg, 1998). Hence, since recently, in addition to defining physical exercise through the concepts of progress mode (i.e., constant or incremental load), intensity (i.e., low, moderate, vigorous), duration (i.e., seconds, minutes, hours) and the physical metabolism supplying the muscles energy (i.e., aerobic and anaerobic metabolism - Audiffren, 2009), *physical exercise is starting to be considered through the concept of cognitive load* (i.e., the amount of cognitive resources required to perform the motor task; Pesce, 2016*;* Burzynska et al., 2017; Müller et al., 2017).

In such context, the first and second parts of my introductory chapter will present a short overview of studies showing that calling-out cognitive functions when performing a physical exercise leads to greater cognitive benefits. Then, the third part will concern the theoretical demonstration that cognitive functions, especially executive functions, are required to perform efficiently a physical exercise.

I. At the start of the exercise-cognition relationship: physical exercise for cognitive benefits

In the context of the necessity to enhance individuals health, the most recent meta-analyses confirmed that performing a single bout of physical exercise (Chang, Labban, Gapin, & Etnier, 2012) or exercising regularly (Colcombe & Kramer, 2003) leads individuals to benefit from an overall improvement in their cognitive functions (e.g., attentional abilities, crystalized intelligence, memory, executive functioning). More specifically, even if a certain amount of studies in the field of sport psychology did not observe such result patterns, when studying all of the actual studies conducted in the field of sport psychology, a low-to-moderate effect size was revealed in favour of a positive effect of both acute and chronic physical exercise on human cognition (Chang et al., 2012; S. Colcombe & Kramer, 2003).

Interestingly, the cognitive enhancements are observed both at a behavioural level through paper-and-pencil and computerized tasks (Chang et al., 2012; Colcombe & Kramer, 2003) and at a neurological level through the measurement of neural activation (Hillman, Snook, & Jerome, 2003) and brain structural changes (Colcombe, Kramer, McAuley, Erickson, & Scalf, 2004). For instance, Hillman and collaborators (2003) observed an increase in the amplitude and a decrease in the latency of the P300 component during an inhibition task (i.e., flanker task) that was performed after a single bout of physical exercise. In cognitive neurosciences, the P300 appears on an electroencephalogram (EEG) 300 ms after the stimulus presentation (Fig. 1) and reflects neuronal activity underlying cognitive functions (Donchin & Coles, 1988; Polich & Lardon, 1997). More specifically, the P300 amplitude would be the tell-tale of the amount of attentional resources allocated towards a stimulus or a task. Thus, an increase in the amplitude would reflect an increase in the attentional abilities (Kok, 2001; Polich, 1987; Polich & Heine, 1996 as cited by Audiffren, 2009). On the other hand, the P300 latency is viewed as a measure of the stimulus identification and classification speed (Kutas, McCarthy, & Donchin, 1977; Magliero, Bashore, Coles, & Donchin, 1984 – as cited by Audiffren, 2009). Thus, a decrease in the latency would reflect an improvement of the individual’s ability to identify and classify stimuli. From such a neuroscientific standpoint, the results obtained by Hillman and collaborators (2003) lead them to suggest that performing a physical exercise induces a transient enhancement of the attentional processes.

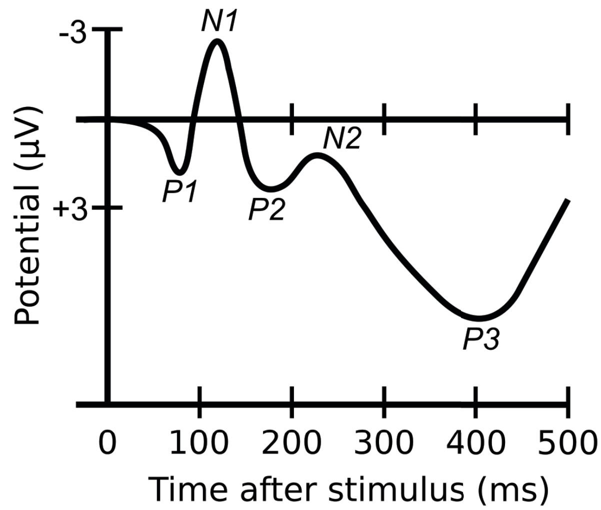


Figure 1: Schematic representation of the event-related potential occurring during the performance of a cognitive or motor task

The first principal hypothesis explaining the cognitive benefits after physical exercise goes through the physiological response framework (Chang et al., 2012). More specifically, in this framework, the cognitive benefits are thought to arise as a consequence of the changes occurring in the heart rate frequency and the oxygenation level in the blood. In addition, exercise may also modify the hormonal efficiency of the system, which would impact cognition. For instance, the levels of brain-derived neurotrophic factor would provide additional proteins to help support the survival of existing neurons, and encourage the growth and differentiation of new neurons and synapses (Erickson et al., 2013). Furthermore, changes in plasma catecholamine would improve the efficiency of neural system for optimal cognitive functioning (Chang et al., 2012). Hence through these physiological effects of physical exercise, several studies have shown that exercising regularly will lead to angiogenesis (Swain et al., 2003), neurogenesis (van Praag, Christie, Sejnowski, & Gage, 1999), greater cerebral plasticity (Voss et al., 2010), greater blood capillaries and higher synaptic density (Colcombe et al., 2004).

A second well developed hypothesis suggests that physical exercise leads to (1) an activation of various arousal systems in the brain and (2) a deactivation of the neural structures, which possess functions that are not critical to maintain exercise. Thus, the Reticular-Activating Hypofrontality model (RAH; Dietrich & Audiffren, 2011; Audiffren, 2016) postulates that the cognitive benefits arise as a consequence of the changes occurring in the brain during and after the performance of a physical exercise. More specifically, the cognitive benefits would emerge from "some processes that activates, or at least reactivates, a neural region that was hitherto not functioning at full capacity" during the physical exercise (Dietrich & Audiffren, 2011, p. 1308). First, the activations of both noradrenergic and dopaminergic metabolic pathways will lead to the stimulation of multiple brain regions. More specifically, the central noradrenergic system belongs to a group of brainstem neuromodulatory systems previously referred to as the ascending reticular activating. Hence, during the course of a physical exercise, the activation of the noradrenergic pathway will enhance the individuals' ability to detect and respond to environmental stimuli thanks to the activation of several cortical and subcortical as the occipital and parietal lobes (Viljoen & Panzer, 2007). On the other hand, an activation of the dopaminergic pathways leads to an enhancement of individuals' working memory (Seamans & Yang, 2004) through the stimulation of a complex network involving temporal and frontal brain areas (Viljoen & Panzer, 2007). However, high levels of noradrenaline (Arnsten and Robins, 2002 – as cited by Audiffren, 2016) and dopamine activation (Cools & D'Esposito, 2011– as cited by Audiffren, 2016) can lead to specific impairments of the cognitive functions supported by the prefrontal cortex such as executive functions. Second, a deactivation of neural structures whose functions are not critically needed to maintain exercise occurs during physical exercise. More specifically, the RAH model suggests that as long as physique exercise requires large muscles groups to be contracted, the brain needs to allocate most of the brain metabolic resources to the regions involved in the sensory motor processes. Hence, the posterior cortex and subcortical regions will benefit from a supra-activation during physical exercise. However, since the brain resources are fixed (i.e., has a limited capacity), the regions which are not involved in the sensory motor processes such as the prefrontal cortex will suffer from a deactivation. As such, the RAH model suggests that during the performance of a physical exercise, an impairment in frontal executive functions would occur as a consequence of a too high a level of noradrenaline, a too high a level of dopamine and a deactivation of the prefrontal cortex (Dietrich & Sparling, 2004). In consequence, because (1) the prefrontal cortex and the executive functions associated are impaired during the physical exercise and (2) some processes activates, or at least reactivates, a neural region that was hitherto not functioning at full capacity (Dietrich & Audiffren, 2011, p. 1308), the logic would then be that a compensatory rebound of executive ability would be observed after physical exercise once the brain resources refill into the frontal areas (Dietrich & Audiffren, 2011). That is may be why, the executive functions benefit the most from physical exercise (Chang et al., 2012; Colcombe & Kramer, 2003).

Unfortunately, both the physiological response hypothesis and the hypofrontality hypothesis are today jeopardized because of a difficulty in understanding empirical work that has been reported. Indeed, the physiological hypothesis does not provide the means for example to understand why the cognitive gains after a physical exercise do not increase through time (Etnier, 2008; Etnier, Nowell, Landers, & Sibley, 2006). On the other side, the hypofrontality theory would predict that an hypoactivation of the frontal brain region occurs while exercising and this is not always the case. More specifically, while conducting their meta-analysis, Rooks, Thom, McCully, and Dishman (2010) reported that a decrease in the prefrontal oxygenation is observed during the performance of a near maximal exercise intensity tolerated by participants. However, when individuals performed a submaximal intense exercise, the prefrontal oxygenation is maintained or even increased. Thus, the results lead researcher to consider that different mechanisms, requiring or not the prefrontal cortex, may occur during a physical exercise. For instance, Audiffren and André (2015) suggested that executive functions may be required to self-regulate one's effort during physical exercise. More specifically, authors considered that continuing an exercise despite pains in some part of the body and continuing to practice in unfavourable conditions (e.g., heat or cold) requires the involvement of executive functions to adjust and control motor output to experience the most positively as possible the session (Audiffren & André, 2015).

Hence, in the present thesis, my work was lead out within the framework of a third theory that develops the idea that **the benefits obtained from physical exercise depends on the cognitive resources that are required during the process of motor planning and execution** (Burzynska et al., 2017; Müller et al., 2017).

II. Calling-out cognitive functions while exercising: the condition for greater benefits

In the societal context of population aging, the necessity to constantly find ways enabling older individuals to improve and/or maintain their independence led Burzynska and collaborators (2017) and Müller and collaborators (2017) to conduct two scientific studies. The aim of these studies was to understand how the motor complexity of a physical exercise may lead to different cognitive improvements and brain changes.

Results revealed that in comparison to non-highly cognitively demanding physical exercise (e.g., walking, stretching), producing cognitively demanding task (e.g., dancing) leads to greater brain changes both in white (Burzynska et al., 2017) and grey brain matters (Müller et al., 2017). More specifically, even if the statistical analyses did not show that dancing allows greater cognitive benefits (i.e., through the conduction of paper-and-pencil tests), authors revealed that dancing leads to a greater conductivity of the fornix white matter after 6 months of weekly practice (i.e., 1h sessions, three sessions per week - Burzynska et al., 2017) and to a greater grey matter volume in the left precentral gyrus both after 6 months (i.e., 90 minutes twice a week during the first 6 months) and after 18 months of practice (i.e., 90 minutes once a week during the last 12 months - Müller et al., 2017). Furthermore, the authors observed that the plasma concentration of the Brain Derived Neurotrophic Factor (BDNF), associated to the neurogenesis in the left precentral gyrus, increased only in the dancing experimental condition from the beginning to the 6 month of the exercise training program (Müller et al., 2017).

The data led authors to suggest that the brain structural changes revealed after a physical exercise would depend on the amount of cognitive resources required for handling that motor task. As a matter of fact, dancing “is a pleasurable and captivating activity, which involves aerobic exercise, sensorimotor stimulation, and cognitive, visuospatial, social, and emotional engagement” (Burzynska et al., 2017, p. 10). Furthermore, it was suggested that dancing "should be regard[ed] as an equivalent of an enriched environment requiring the ability to learn constantly new choreographies, to integrate multisensory information, to coordinate the whole body and to navigate in space”. This is why dancing is considered as an activity that provides an individual with a global rich experience of sensory, motor and cognitive stimulations (Kattenstroth, Kalisch, Holt, Tegenthoff, & Dinse, 2013). Consequently, due to the higher cognitive stimulations occurring during the motor performance of a dance physical exercise, this practice would lead to greater brain changes in comparison to other experimental conditions (Burzynska et al., 2017; Müller et al., 2017).

The results indicating that dancing leads to greater brain changes in comparison to other types of physical exercises, echo those revealing that combining physical exercise and cognitive interventions allow greater cognitive, physical and mental health improvements in comparison to performing either cognitive or physical activities alone (Bamidis et al., 2015; Lauenroth, Ioannidis, & Teichmann, 2016; Oswald, Gunzelmann, Rupprecht, & Hagen, 2006). Similar conclusions have been reached in animal studies in the context of "enriched environments". For example, Kempermann and collaborators (2010) showed in rodents that combining an enriched environment and the possibility to being physical active leads to greater hippocampus neurogenesis in rodents than living only in an enriched environment. Combining cognitive stimulations and physical exercise has thus the power to overpower the benefits of both cognitive and physical exercise when they are performed alone.

The results reported by Burzynska and collaborators (2017) and by Müller and collaborators (2017) are all of the more powerful that: (1) the benefits observed for the white matter were independent from the individuals' cardiorespiratory fitness baseline and the individuals' weekly amount of physical exercise baseline (Burzynska et al., 2017) and that (2) the benefits observed for the grey matter and the BDNF plasma concentration were independent from the individuals' cardiovascular fitness levels during physical exercise (Müller et al., 2017). The interesting point of these results is that they echo those revealing that aerobic fitness gains were neither necessary, nor sufficient to achieve cognitive gains as a result of exercise programs (Etnier et al., 2006). Thus, the cognitive gain from physical exercise may depend neither only on the physiological factors occurring during or after a session nor only on the fitness level of individuals. In fact, the results obtained by Burzynska and collaborators (2017) and Müller and collaborators (2017) suggest that cognitive benefits from physical exercise may also depend on the cognitive resources required to prepare and to perform the motor task. ***But why does physical exercise require cognitive abilities?***

III. Dealing with the origins of human cognition to understand their involvement in physical exercise

Human Cognition is defined as "the mental processes associated with attention, perception, thinking, learning, and memory" (Loring & Meador, 1999). For a long time, in the framework of cognitivism, the cognitive functions were considered as abilities belonging to humans only (Cisek & Kalaska, 2010; Koziol, Budding, & Chidekel, 2011; Koziol & Lutz, 2013) and as functions independent on the low level sensorimotor processes. Furthermore, cognitive functions were thought to emerge from the need by our ancestors to solve survival problems such as communicating, prey stalking, disease avoidance, mate choice or coalition formation (Heyes, 2012). However, the embodiment framework suggests that throughout their evolution, humans' organism was constantly faced with a complex and ever changing environment; leading to a potentially bewildering variety of opportunities and demands for action (Cisek & Kalaska, 2010; Heyes, 2012). Thus, in order to strive and interact safely, humans were required to elaborate high-level mechanisms enabling them to select the best fit and to perform the most efficient voluntary motor behaviour in a given context (Cisek & Kalaska, 2010). Thus, cognitive functions may have been elaborated for the need to select and to control efficiently intention motor activities rather than for thinking (Koziol & Lutz, 2013).

Several studies have since confirmed that *sensorimotor processes are at the core of human cognitive functioning* (Loeffler, Raab, & Cañal-Bruland, 2016).

First, from a phylogenetically standpoint, the analyses of the brain structures reported by Barton (2012) show that the neocortex (i.e., associated with higher cognition, such as planning and executive control) and the cerebellum (i.e., associated with sensorimotor processing) have phylogenetically evolved together. More specifically, the analyses revealed that, when considering the brain of different species and by controlling for the species' body mass, the phylogenetically evolution of the brain was a product of both independent and co-ordinated changes in neocortex and cerebellum. These results lead to suggest that human cognition (i.e., associated with neocortex elaboration) may phylogenetically be elaborated in relation to the development of sensorimotor processing (i.e., associated with cerebellum elaboration) (Cisek & Kalaska, 2010; Heyes, 2012; Koziol & Lutz, 2013).

Second, in psychology, the Piaget's theory of cognitive development (1936) was the first to put forth the possibility that, during childhood, the development of the cognitive functions is related to the development of the sensorimotor processes. More specifically, throughout the maturation, child's motor skills increase the possibilities to explore and understand the environment, leading to more and more differentiated cognitive structures (Piaget & Inhelder, 1966) and cognitive concepts (such as object permanence or tool use). For instance, Smith (2005) revealed that previously performing a movement alters the children's ability categorisation. More specifically, performing horizontal or vertical movements with a new object led children to categorize other objects as a function of the previously movement performed. In this study, children were asked to look at an experimenter moving an object (i.e., a non-defined object called a "wug" by experimenter) either following a vertical or a horizontal axis. After watching the experimenter producing the movement, children were asked, in the action condition, to reproduce the same movement (i.e., either a horizontal movement or a vertical one). In the non-action condition, children were not asked to reproduce any movement. Then, in the last part of the experimental condition, children were faced to non-defined different objects (i.e., a horizontal and a vertical one) and had to choose which one of the two objects can also be called a “wug”. Results showed that reproducing the action of the experimenter but not watching it altered the children’s categorization of objects. More specifically, author revealed that previously performing a horizontal movement lead children to categorize the horizontal object as a “wug” while they did not categorize vertical object as a “wug”. Furthermore, previously performing a vertical movement lead children to categorize the vertical object as a “wug” while they did not categorize horizontal object as a “wug”.

Nonetheless, even if a relationship was revealed between human cognitive elaboration and sensorimotor processes, all motor developmental abilities are not associated to the development of all of cognitive functions. More specifically, through the production of a systematic review, Van der Fels and collaborators (2015) revealed that while the elaboration of fluid intelligence (i.e., capacity to reason and solve novel problems, independent of any knowledge from the past) seems to be a function of the development of individuals’ fine motor, bilateral coordination or object controlled movement abilities, the elaboration of crystallized intelligence (i.e., ability to use skills, knowledge, and experience) seems to depend only on the development of gross motor ability.

Finally, at a neurological level, data revealed that the brain networks required for the cognitive functioning overlap those required for motor control (Desmond, Gabrieli, Wagner, Ginier, & Glover, 1997; Diamond, 2000). More specifically, although the cerebellum was considered for a long time as only useful for motor control, this brain area was revealed as playing a critical role in most of the cognitive functions such as emotional process, learning, memory, empathy or decision-making (for a review see Barton, 2012), verb generation, planning, tasks requiring the learning and memory of arbitrary associations, set-shifting tasks and working memory tasks (for a review see Diamond, 2000). Such overlap is confirmed by the fact that the impairment of one impacts the efficiency of the other (for a review see Diamond, 2000). Furthermore, it was revealed that an innate stroke of the motor areas can impact children arithmetic abilities (van Rooijen et al., 2012) while an acquired stroke of motor areas can influence adults visual processing (Bartolo, Carlier, Hassaini, Martin, & Coello, 2014).

Overall, these studies confirm the importance of the integrity of the motor brain network for efficient cognitive functioning. This view has furthermore been developed in the embodied model of cognitive functions that defends the idea that the principles underlying human cognitive functioning are common to those underlying the control of physical movement (Rosenbaum, Carlson, & Gilmore, 2001). ***But how may one explain that during the course of a movement, cognition is required?***

IV. The role of human cognition when actually moving

During the course of "on-line" daily living, a person interacts constantly with an environment that requires a continuous evaluation of alternative activities that may become relevant in regard to the environmental changes (Cisek & Kalaska, 2010). As such, before acting, through the use of the forward loop (Fig. 2) and the dorsal stream (Fig. 3), the brain will plan, predict and anticipate the motor goal and the sensorial consequences of the actions that may be relevant in a given context. In other words, the brain will *specify* the spatiotemporal and the motor aspects of every possible action (for a review see Cisek & Kalaska, 2010).

Thereafter, since multiple actions usually cannot be performed at the same time, the brain must to *select* the most relevant behaviour that will be performed. Hence, an intelligent system will elaborate a selecting process through factors related to rewards, costs, risks, or any variable pertinent for making good choices (Cisek & Kalaska, 2010). To do so, the brain will call-out both sub-cortical and cortical areas (Fig. 3). Then, the brain will send the efference to the muscles to perform the task.

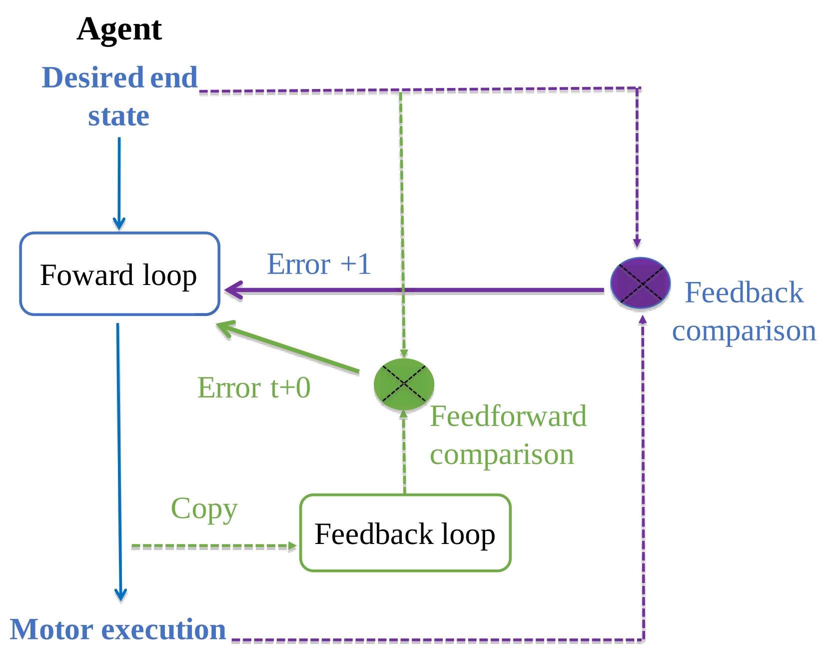


Figure 2: Schematic representation of both forward and feedback loop when planning and re-adjusting motor output

When actually performing the motor behaviour, through the use of the feedback and feedforward loops, a comparison between the predicted sensorial feedback and the actual one is conducted (Fig. 2). If the actual sensorial consequences of the action correspond to the predicted ones, the motor goal is achieved and the motor behaviour terminated. However, in a case of a discrepancy between the actual and the predicted feedback the brain will send a new motor program to the muscle in order to attain the anticipated, predicted and desired goal (Fig. 2 and 3) (Jeannerod, 2006).

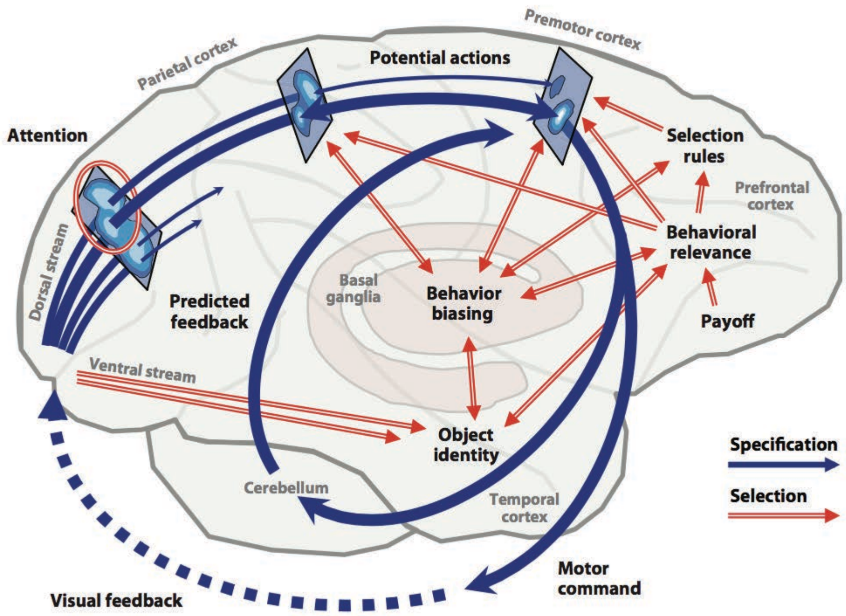


Figure 3: Sketch of the affordance competition hypothesis in the context of visually-guided movement. The primate brain is shown, emphasizing the cerebral cortex, cerebellum, and basal ganglia. Dark blue arrows represent processes of action specification, which begin in the visual cortex and proceed rightward across the parietal lobe, and which transform visual information into representations of potential actions. Polygons represent three neural populations along this route. Each population is depicted as a map where the lightest regions correspond to peaks of tuned activity, which compete for further processing. This competition is biased by input from the basal ganglia and prefrontal cortical regions that collect information for action selection (red double-line arrows). These biases modulate the competition in several loci, and because of reciprocal connectivity, their influences are reflected over a large portion of the cerebral cortex. The final selected action is released into execution and causes overt feedback through the environment (dotted blue arrow) as well as internal predictive feedback through the cerebellum.

Such kind of brain activation was confirmed by Neubert and collaborators (2010). More specifically, through the conduction of three different studies, authors showed that when reprogramming a movement, the presupplementary motor area (pre-SMA) and the right inferior frontal gyrus (rIFG) will respectively facilitate and inhibit the primary motor cortex. Interestingly, while short latency responses call-out only direct cortical routes, long latency responses will be influenced by the activity of the subcortical structures.

Hence, in the perspective of survival and safe development, developing cognitive functions enabling humans to anticipate and predict the sensorial consequences of their motor behaviours was primordial. In addition, developing memory abilities enabling them to remember the consequences of their previous actions was an helpful cognitive ability for selecting the more relevant motor behaviour in a given context. Interestingly, among the amount of cognitive resources that was created, some emerged for the integration of information emerging from different cortical and subcortical regions while inhibiting the non-relevant cues.

V. Executive functions and self-regulation for adapted motor behaviour

The executive functions are defined as the most evolutionary elaborated cognitive functions for controlling, regulating and adjusting behaviour (Koziol et al., 2011). As such, executive functions would play a key role in integrating the information emerging from different cortical and subcortical regions in order to maintain a goal-oriented behaviour (Blair & Ursache, 2011; Otero & Barker, 2014).

Since the well pioneering article of Miyake and collaborators (2000), executive functions concern the elementary component of shifting, updating and inhibition abilities (Miyake et al., 2000). The shifting ability refers to an individual's ability to shift back and forth between multiple tasks, operations or mental sets (Monsell, 1966 – as cited by Miyake et al., 2000). The updating ability refers to the monitoring and the coding of incoming information for relevance to the task at hand

and, then appropriately revising the items held in working memory by replacing old, no longer relevant information with newer, more relevant information (Morris & Jones, 1990 – as cited by Miyake et al., 2000). Thus, the essence of updating lies in the requirement to actively manipulate relevant information in working memory rather than to passively store the information (Miyake et al., 2000). Finally, the inhibition ability concerns one's ability to voluntary inhibit dominant, automatic or prepotent responses when necessary (Miyake et al., 2000).

At a brain level, studies have shown that in addition to requiring the activation of the prefrontal cortex during the performance of cognitive tasks assessing executive function brain requires the activation of both posterior (Buss & Spencer, 2017) and temporal structures (Takeuchi et al., 2013). Hence, while the executive functions are usually associated to the activation and the development of the prefrontal cortex the efficacy of this cognitive ability does not depend only on the development of the prefrontal cortex (Cisek & Kalaska, 2010; Koziol et al., 2011). Indeed, since the executive functions were elaborated for survival through efficient motor control other species are doted by this ability (Cisek & Kalaska, 2010; Koziol et al., 2011); leading to the activation of other structures than the most developed one in Humans.

To confirm the role of executive for motor control abilities, Gottwald, Achermann, Marciszko, Lindskog and Gredebäck (2016) conducted a study revealing that the more efficient the children's executive functioning was, the more their motor control ability was developed. More specifically, children's ability to inhibit non-relevant behaviour and to update required and relevant information were revealed as correlated to their ability to plan motor behaviour as a function of their goals and the environmental constraints. To obtain such results, the authors asked children to perform three different tasks. First, in the prospective motor control task, children were asked to reach for an object (i.e., a plush toy plum, 2cm in diameter) and to place it in a wooden box (i.e., large, medium or small). In such a case, children had to plan their behaviours as a function of the box in which they had to put the toy. More specifically, while putting the toy in a small box requires more precision and low movement, putting the toy in a large box enables individuals to be quicker. Here, the peak velocity of the first movement was the dependant variable. In the inhibition task, children were faced to an object and were asked to not touch it during the first 30 seconds of the presentation. The time during which children were able to inhibit their desire to touch the object was the dependant variable. Finally, in the updating task, children were asked to search an object hidden in a small chest of four drawers while the location of the object was changed in each of the four test trials. In this task, the numbers of children's success were the dependant variable. When studying the dependant variables, authors revealed that the performance in the updating and in the inhibition tasks were correlated to the level of performance in the prospective motor task. This led authors to conclude that before being allocated to the management of multiple task, executive functions are elaborated for prospectively motor control. Thus, whereas the motor system would be engaged in achieving low-level goals such as reaching for a ball while reducing error in performance and adjusting to the environment (Wolpert, Diedrichsen, & Flanagan, 2011), executive functions are related to goals on a higher cognitive level that do not directly deal with the movements of individual joints but rather with the long-term benefits of the system as a whole (Barkley, 2012).

To fully understand the importance of executive functions in motor development, Roebers and collaborators (2014) showed that when assessing the relationship between the development of motor control and children's cognitive abilities used for school achievement, the executive functions modulates the relationship. More specifically, authors conducted a longitudinal study in which they revealed that when assessing children's school achievement at 2 years, both their motor skills and their IQ measured the last year predicted their performances. However, when authors added the children's executive functions as a factor of the prediction, both the motor skills and the IQ lost their predictive power; leading to suggest that if we want to study the relationship between motor abilities and human cognition, the role played by executive functions must be considered. Indeed, for example, it was revealed that the more executive functions are preserved after stroke, the more individuals are able to recover physically and cognitively from it (Hayes, Donnellan, & Stokes, 2013).

Interestingly, in sport psychology, the key role of executive functions for efficient motor control is often associated to another concept under the often considered terms of self-regulation (Buckley, Cohen, Kramer, McAuley, & Mullen, 2014) and self-control (Audiffren & André, 2015). The self-regulation is a process that allows organisms to guide their behaviour in the pursuit of theirs goals – desired end states they are committed to (Gendolla, Tops, & Koole, 2015). Hence, self-regulation is a vital capacity that allows people to guide their behaviour by managing and mastering their thoughts, motor objectives and social intentions as a function of their goals, their abilities and the environmental constraints. Thus, it was suggested that the way one manages his/her biological and psychological resources, modifying the manner in which individuals approach and overcome the challenges of everyday life (e.g., learning new skills, adapting to environmental changes; Tomporowski, 2008). On the other side, self-control is viewed as a limited resource that is depleted when people engage in behaviours that require self-regulation. Thus, when people engage in motor behaviours which require more cognitive resources than baseline reference levels, they negatively experience what they are doing. Conversely, performing a task that we can cognitively handle leads to positive experiences. Hence, today, with a more translational approach, executive functions may provide the means to coordinat[e] the cognitive abilities with motivation and affect in order to fulfil biological needs in relation to the conditions at the time (Koziol, Budding, & Chidekel).

VI. Conclusion

In regard to the present chapter, we can argue that cognitive functions and especially executive functions can be useful to perform and self-regulate a physical exercise. However, for both the survival and the development of Human species, the way one experiences a situation in the present may help to efficiently select the most relevant motor behaviour in the future. In fact, as reconsidered by Cisek and Kalaska (2010), the memory of previous emotions and the actual affective states of an individual during whole body movement help for efficient selection the most relevant behaviour to perform. Thus, the next introductory chapter of this manuscript develops the essential role played by the affective states in the adjustment of motor behaviour, in the specific context of physical exercise.

Chapter 3:

The essential role of Affective States and Tolerance to effort to reveal individual differences

I. Definition

Affective states are defined as an inclusive psychological construct referring to accessible evaluative feelings in which a person feels good or bad or likes or dislikes what is happening (Gray, & Watson, 2007, p. 107). Thus, affective states are now considered as being part of the field of research of emotions, physical sensations, attitudes or even moods (Fredrickson, 2001). From a survival standpoint, affects are considered as a neurophysiological state, not cognitive or reflective (Russell, 2003) always available to consciousness (Russell, & Barrett, 2009) and ***providing the primary means by which information about critical disruptions of homeostasis enters consciousness*** (Cabanac, 1979; Panksepp, 1998 – as cited by Ekkekakis, 2013). Hence, affective states are considered as essential "ancient" and "primitive" components (Ekkekakis, 2013) without it we would probably have no inclination to move toward or away from anything, jeopardising our survival (Batson, 1992, p. 309 - as cited by Ekkekakis, 2013). Thus, thanks to their power to guide humans' motor behaviours, affective states have been conceptualized as "the primary motivational system in human beings" (Tomkins, 1962, p 108 – as cited by Ekkekakis, 2013). ***But how affective states can actually influence adaptive motor behaviour?***

II. Motor cognitive and affective states

In the field of motor cognition, the essential role of affective states is to inform individuals about what they are doing in comparison to what they were expecting to occur. More specifically, during the course of a motor behaviour, affective states are suggested as ***emerging from the discrepancy that may occur between the predicted and the actual sensorial information*** when the comparison is made (Carver, & Scheier, 1998; Frijda, 1988; Frijda, 1986 - as cited by Carver, Johnson, Joorman, & Scheier, 2015). In this case, feelings with a positive valence would mean that you are doing as well as or better than expected. Inversely, affective states with a negative valence would mean that you are doing worse than expected (Carver, & Scheier, 1998 - as cited by Carver, et al., 2015). For sure, as much as the motor behaviour is conducted, the feedback system related to affective states works; leading affective states to be a constant conscious representation of the discrepancy that may occur within the action system. Hence, this cognitive conception supports the theoretical idea that affective states are essential to guide, self-regulate and optimize adaptive motor behaviour.

The aim of my thesis work was to study the possibility of using the affective states to gain a better understanding of the on-line adjustment of motor behaviour during the course of a physical exercise.

III. Affective states during physical exercise: the theoretical framework of a cognitive and physiological tell-tale

In sport psychology, the dual mode theory suggests that the way one experiences a physical exercise emanates from (1) the physiological changes occurring during the motor task, (2) the individuals' cognitive characteristics and (3) the interplay between the two (Fig. 4; Ekkekakis, 2003). However, to consider affective states as a way to guide and self-regulate motor behaviours during physical exercise, three things must be highlighted.

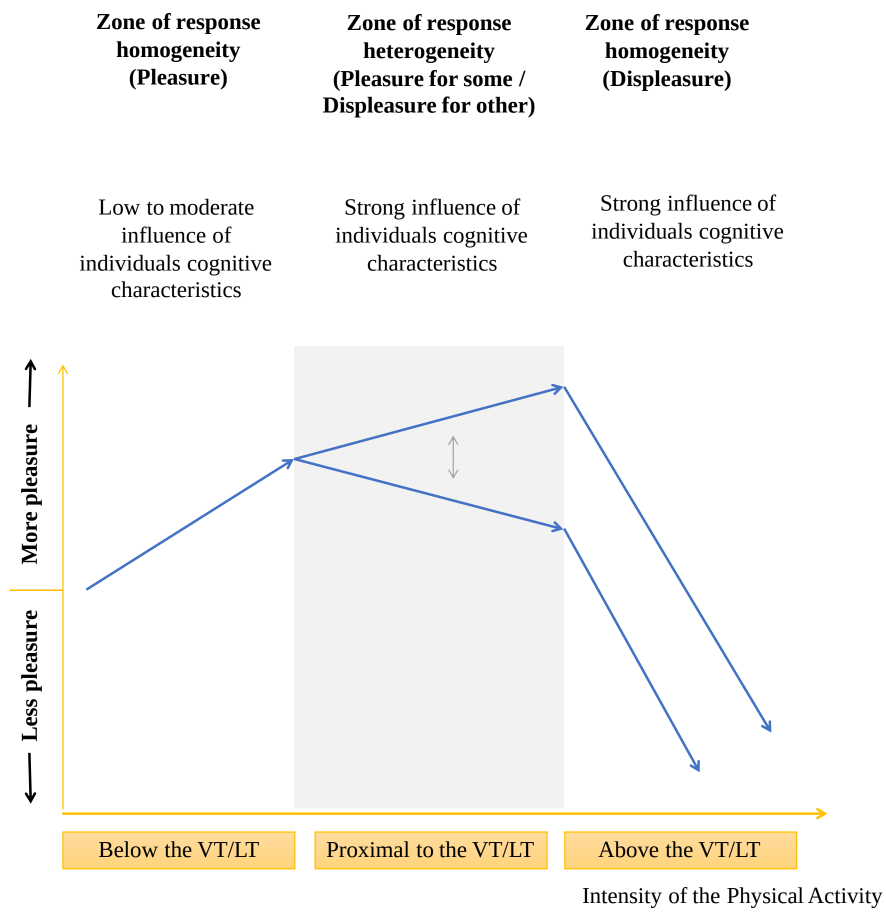


Figure 4: Schematic representation of the dual mode theory reflecting that the way one experiences a physical exercise emanates from (1) the physiological changes occurring during the motor task, (2) the individuals' psychological characteristics and (3) the interplay between the two (VT - Ventilatory Threshold; LT – Lactate Threshold; Ekkekakis, 2003).

First, performing a whole-body movement requires the production of muscle energy to handle physically the task. The energetic production can occur through either the aerobic or the anaerobic metabolisms. The aerobic metabolism will require the use of the oxygen to produce the muscle energy. On the other hand, the anaerobic metabolism will require the use of an individual’s muscle energetic reserve to handle the physical demands of the motor task. In such a context, while one will allow individuals to exercise with the minimum amount of pain or fatigue (i.e., the aerobic metabolism), the accumulation of lactate by the use of the anaerobic metabolism will lead to fatigue, pain and even exhaustion. Hence, exercising physically at an intensity requiring the anaerobic metabolism will lead to negative affective states, while moving through the aerobic metabolism may lead to the expression of more positive affective states.

Second, individuals’ psychological characteristics may play a role in the way they experience positively or negatively a physical exercise. For instance, it was revealed that the more individuals are confident in their abilities to handle a physical exercise, the more they will positively experience a session. In the context of motor cognition, we can suppose that the efficiency of an individual’s motor control can influence/impact the way one experiences positively or negatively a single bout of physical exercise. In fact, affective states are defined as the tell-tale of the constant discrepancy between predicted and actual sensorial information during motor production. Hence, possessing accurate motor prediction abilities, efficient motor cognition and sensitive detectors of motor errors will lead individuals to experience more pleasurable instants during the course of physical exercise, because less in the state of error.

Third, errors in predictions do not have the same consequences as a function of exercise intensity. More specifically, the point of transition between predominantly aerobic energy production and anaerobic energy production (Ventilatory Threshold - VT) is an intensity of practice at which non-efficiently predictive process may lead to highly threatening consequences. Exercising below the VT means using predominantly the aerobic metabolism to perform the task. In such a case, the homeostasis, i.e., a constant energy stream for exercise, simply by breaking down carbohydrates and fats through the use of aerobic metabolic processes, is not threatened physiologically. Furthermore, thanks to the constant use of the aerobic metabolism, errors made by the predictive process will not lead to a threatened homeostasis state but will only require a re-adjustment of the motor output. However, performing at/around the VT is more risk related for individuals. At this intensity due to the higher involvement of the anaerobic metabolism to support the muscle energy production, the homeostasis state is fragile and risks to be lost as soon as the VT threshold is crossed. Hence, at this intensity of practice, being able to perform the task throughout time requires individuals to predict efficiently the consequences of their motor behaviour without making error. If they do not, a possible greater threat of homeostasis exists due to the necessity to allocate cognitive resources to re-adjust the motor output whereas resources are needed to maintain homeostasis and stability within the system; leading individuals to stop the motor production.

During incremental exercise using production procedures, VT appears when the physical activity is produced and perceived as *"somewhat difficult"* (RPE 13 on the 6–20 Borg Scale) in active males when running (Stojiljković et al., 2004) and athletes when cycling (Feriche, Chicharro, Vaquero, Pérez, & Lucía, 1998). The Borg Scale of Perceived Exertion is often used to match how hard one *feels and experiences the difficulty of a practice* session (Borg, 1998). In the scientific literature, it was revealed that RPE Borg Scale scores correspond to objective indexes of physical exercise intensity such as individuals' heart rate frequency or oxygen consumption (Eston, 2012). The RPE Borg Scale was also revealed as allowing individuals to produce different physical exercise intensity as a function of their inner feelings of effort (Eston & Williams, 1988; Feriche et al., 1998; Stojiljković et al., 2004). These observations echo those revealing that asking individuals to produce physical exercise while focusing on their affective states such as the pleasure/displeasure experienced during the motor behaviour helps to self-regulate physical intensity (Lind, Joens-Matre, & Ekkekakis, 2005; Rose & Parfitt, 2008), to improve running performances by optimizing the management of energy expenses (Schücker, Knopf, Strauss, & Hagemann, 2014), and to experience more pleasantly the session in comparison to a physical exercise performed at an intensity set by the experimenters (Parfitt, Rose, & Burgess, 2006). Hence, even if the evidence to use the affective states as a primary method of prescribing exercise intensity is viewed for some as being insufficient (Garber et al., 2011), the patterns of results defend the opposite. In fact, the afore mentioned studies demonstrate that affective states can intuitively be used as a guide for both active and inactive individuals to guide their motor behaviour while exercising (Eston & Williams, 1988; Lind et al., 2005; Ekkekakis, & Acevedo, 2006; Rose & Parfitt, 2008; Schücker et al., 2014). Furthermore, the power of using the individuals' affective states as a way to select the intensity of a physical exercise is all the most relevant since the affective states experienced during a session predict the degree of engagement in a future practice (Jekauc, 2015; Trost et al., 2002; Zenko et al., 2016).

Nevertheless, few studies have tried to reveal how the perception of effort may be use as a useful guide to self-regulate motor behaviour *throughout time*. The aim of my thesis work was to study the possibility of using this affective state to gain a better understanding of the on-line adjustment of motor activity during the performance of "somewhat difficult" physical exercise. However, what does "somewhat difficult" mean? We are not equal when considering motor control abilities. More importantly, we are not equal in the perception and tolerance to our inner affective states. Hence, my thesis work deal with the importance to consider one individual's tolerance ability when studying physical exercise dynamic.

IV. Profiling individuals for pleasurable physical exercise: the neuropsychology of Tolerance to effort

The tolerance to exercise intensity is defined as a trait that influences one's ability to continue exercising at an imposed level of intensity when the activity becomes uncomfortable or unpleasant (Ekkekakis et al., 2005). To date, tolerance score has been shown to be predictive of the feelings experienced during physical practice (Ekkekakis, Hall & Petruzzello, 2005), the ability to continue a physical exercise after the VT occurrence (Ekkekakis, Hall & Petruzzello, 2005), the physical effort produced (Hall, Petruzzello, Ekkekakis, Miller, & Bixby, 2014) and the oxygen consumed (Schneider & Graham, 2009). The concept of Tolerance was developed in a physiological framework considering that all individuals are no equal to tolerate pain or sensorial discomfort. Hence, research into the mechanisms determining exercise tolerance has focused on the cardiovascular, respiratory, metabolic, and neuromuscular mechanisms of muscle fatigue (McKenna & Hargreaves, 2008). Nonetheless, through the theoretical framework of embodiment, we can hypothesize that the physiological differences observed between low and high tolerant individuals may be observed at a cognitive level. More specifically, individuals who are characterised by higher level of physiological tolerance should be characterised by higher level of cognitive control. Inversely, those defined by low level of tolerance should be defined by lower level of cognitive control.

In such context, the aim of my thesis work focused on the concept of Tolerance to effort. However, throughout the studies conducted in this thesis work, the perception of effort was used to set physical exercise production. In consequence, the experiment focused on the study of one's ability to continue exercising at an *imposed level of perception of effort* when the activity becomes uncomfortable or unpleasant. Thus, throughout the rest of the present manuscript the term "Tolerance of exercise intensity" was changed into the term of "Tolerance to effort". The theoretical hypothesis was that Low tolerant individuals possess less efficient cognitive control and less efficient abilities to self-regulate their motor behaviour while exercising as a function of the effort they are perceiving during physical exercise; leading them to experience less positively their motor performance than High Tolerant individuals.

My PhD research was conducted mostly in "healthy" individuals with four objectives in sight.

(1) ***Confirm that physical exercise can be defined from a cognitive standpoint due to the cognitive resources required to perform it.*** A better definition of the prescribed physical exercise may lead to better prescription as a function of individuals abilities to cognitively handle the motor task.

(2) ***Determine how Tolerance to effort may predict (1) the way one is able to self-regulate the intensity of a motor production during a "somewhat difficult" physical exercise and (2) how one will experience positively or negatively the motor task.*** A better understanding will give us the possibility to adapt and prescribe more individually a physical exercise in order to minimize negative affective states during practice. Thus, possibly enhancing the motivation of people to engage in regular practice.

(3) ***Understand the physiological concept of Tolerance to effort from a cognitive standpoint.*** In the framework of embodiment, Low Tolerant individuals may present less efficient motor control due to their less efficient abilities to handle physical difficulties and resist to pain or discomfort.

(4) ***Propose new experimental designs to enable a transfer to the clinical field***. The transferability question is primary geared at comparing both healthy and clinical populations, but

also to assess the efficiency of different interventions as a function of population age and pathology.

Part 2

EMPIRICAL STUDIES

Study I

The Psychometric Properties of The Preference for and Tolerance of Exercise Intensity Questionnaire (PRETIE-Q) in French-Speaking individuals

In preparation for submission in Personality and Individual differences

Mauraine CARLIER[1], Panteleimon EKKEKAKIS[2], Laurence DESJARDINS-CREPEAU[3], Louis BHERER[3] & Yvonne DELEVOYE-TURRELL[1]*

[1]SCALab, UMR CNRS 9193, Department of psychology, University of Lille, Lille, France
[2]Department of Health and Human Performance, Iowa State University, IA, USA
[3] Cognitive Health and Aging Research Lab, University of Montréal, Montréal, Québec

***** Corresponding author
E-mail: yvonne.delevoye@univ-lille3.fr (YD)

These authors contributed equally to this work.

HIGHLIGHTS

1. The translation process succeeded in a questionnaire well understood by active and inactive adults.
2. The statistical analyses conducted only on the Tolerance subscale leads to a good construct of the French-speaking version of the questionnaire.
3. The Tolerance to effort subscale was validated in European individuals independently of their self-reported weekly physical practice.
4. The statistical analyses conducted only on the Preference subscale leads to a poor construct of the French-speaking version.

I. Introduction

Studies conducted in the field of health promotion revealed that the way one experience a physical exercise may predict his/her future practice (Jekauc, 2015; Mohiyeddini et al., 2009; Zenko et al., 2016). However, while some individuals are able to positively experience a physical exercise session, some others are not (Backhouse et al., 2007; Van Landuyt et al., 2000). The absence of positive experience during the course of physical exercise may explain why 40 to 65 % of individuals initiating exercise programs are predicted to dropout within 3 to 6 months (Annesi, 2003). In such context, it was suggested that studying the psychological mechanisms and the barriers responsible for the affective responses to physically exercise may be an intelligible way to better understand physical exercise adherence (Ekkekakis et al., 2008a; Wienke & Jekauc, 2016).

In 2005, Ekkekakis, Hall and Petruzello (2005) suggested that we should take into account what kind of physical exercise individuals *prefer* and can *tolerate.* In 2013, the American College of Sports Medicine support this idea by considering it as a way forward more efficient promotion of exercising health behaviours (ACSM, 2010). Preference for exercise intensity was defined as a ‘‘predisposition to select a particular level of exercise intensity when given the opportunity” (e.g., when engaging in self-selected or unsupervised exercise). Tolerance of exercise intensity was defined as ‘‘a trait that influences one’s ability to continue exercising at an imposed level of intensity beyond the point at which the activity becomes uncomfortable or unpleasant’’ (Ekkekakis et al., 2005, p. 354). For now, Preference has been shown to be predictive of the feelings experienced during physical practice (Ekkekakis et al., 2005), the ability to continue a physical exercise at the VT occurrence (Ekkekakis et al., 2005), the variance in the percentage of oxygen uptake associated with the ventilatory threshold at Minute 15 and Minute 20 of the session at self-selected intensity (Ekkekakis, Lind, & Joens-Matre, 2006), the physical effort produced (Hall et al., 2014) and the frequency and intensity of weekly physical practice (Ekkekakis, Thome, Petruzzello, & Hall, 2008b; Smirmaul, Ekkekakis, Teixeira, Nakamura, & Kokubun, 2015). On the other hand, Tolerance score has been shown to be predictive of the feelings experienced during physical practice (Ekkekakis et al., 2005), the ability to continue a physical exercise after the VT occurrence (Ekkekakis et al., 2005), the physical effort produced (Hall et al., 2014), the oxygen consumed (Schneider & Graham, 2009) and the frequency and intensity of weekly physical practice (Ekkekakis et al., 2008b; Smirmaul et al., 2015).

Such results were possible thanks to the use of the PRETIE-Q questionnaire. The PRETIE-Q questionnaire developed by Ekkekakis and collaborators (2005) consists of two 8-item scales, namely Preference and Tolerance, in which each item accompanied by a 5-point response scale. The eight-item Tolerance scale contained four items that targeted high exercise tolerance (e.g., ‘‘I always push through muscle soreness and fatigue when working out’’) and four that targeted low exercise tolerance (e.g., ‘‘During exercise, if my muscles begin to burn excessively or if I find myself breathing very hard, it is time for me to ease off’’). Each item was composed of a 5-point response scale (1 = ‘‘I totally disagree’’; 2 = ‘‘I disagree’’; 3 = ‘‘Neither agree or disagree’’; 4 = ‘‘I agree’’; 5 = ‘‘I strongly agree’’). A high score of tolerance to exercise corresponds to a high capacity to pursue the physical activity although it becomes uncomfortable or unpleasant. A high score of preference for exercise corresponds to a preference for high intense physical activity (Ekkekakis et al., 2005). Both scales have demonstrated high internal consistency, from 0.80 to 0.89 (Ekkekakis et al., 2005, 2008a; Hall et al., 2014), as well as good 3- and 4-month test-retest reliability, ranging from 0.67 to 0.85 (Ekkekakis et al., 2005).

In France, the difficulty to efficiently promote physical exercise physical exercise in the population is quite the same in comparison to the rest of modern societies. The latest research carried out for the Ministry of Health showed that 84% of French people, aged between 15 and 75 years, have been physically active during the past year. Furthermore, among the 84% of active individuals only 46% have a sufficient regular practice to benefit from the real health benefits (i.e., a practice of more than 10 minutes per day) (Inserm, 2008). Finally, only 11% of girls and 25% of boys were revealed as physically exercise in line with the recommendations (Inserm, 2008). Hence, in regards to the necessity to better promote the regular practice of a physical exercise in France, the objective of this original experimental research is to validate the concepts of Preference for and Tolerance of exercise intensity in a European French-speaking population (PRETIE-Q; (Ekkekakis et al., 2005).

II. Method

The French-speaking validation of the Preference for and Tolerance of the Intensity of Exercise Questionnaire (PRETIE-Q) consisted in three parts. The first (Part A) involved the translation and back translation of the PRETIE-Q with the purpose of producing a French-speaking version of the instrument. The second part of analysis (Part B) consisted of a psychometric assessment of the French-speaking version that included the construct validation of the tool in individuals whose first language was French (French and Belgian nationality).

Part A. Translation to create a French version of the PRETIE-Q (PRETIE-QF)

Firstly, two forward translations (T1 and T2) were performed from English (i.e., the original language) into the French-speaking language. The translators, whose mother tongue was French, produced T1 and T2 independently (*Stage I*). One translator had postdoctoral experience in motor cognition and spoke English fluently. This translator was not aware of the concepts being examined in the instrument. The other translator was a PhD student in motor cognition and cognitive psychology and spoke advanced English. This translator was aware of the concepts being examined in the instrument. Both produced their forward translations in written form. Subsequently, a synthesis of these translations was performed by the authors of the present study through mutual consensus, generating a unique common translation (T12) (*Stage II*). From this unique common translation, two back-translations were done *(Stage III)*. One back-translation was performed by a native English speaker who had lived in France for several years, thus having mastered the French language at an advanced level (T3). This person was neither aware of the research purpose nor had a background in physical education, exercise science or related fields. A second translation was performed by a native English speaker who had lived in France for several years, thus having mastered the French language at an advanced level (T4). This person was aware of the research purpose and had a background in physical education, exercise science, motor cognition and cognitive psychology. Both produced their back-translations in written form. Subsequently, a synthesis of these translations was performed by the authors of the present study through mutual consensus, generating a unique common back-translation (T34) (*Stage IV*).

The semantic, idiomatic, cultural, and conceptual equivalence of items was evaluated by two physical education specialists, and by the two forward translators (*Stage V*).

The translation phase was followed by a pre-testing stage with students (N = 112, $mean_{age}$ = 22,46 ± 4,21 years, $mean_{BMI}$ = 24,84 ± 7,47 kg.m-^{2}) in cognitive psychology and sport sciences in order to detect any problems in the comprehension of the questionnaire (*Stage VI*).

The different translations and back-translations provided the means to obtain a French version of the PRETIE-Q (PRETIE-QF - Annex A). In the pre-testing stage, no participants reported misunderstanding of any of the items.

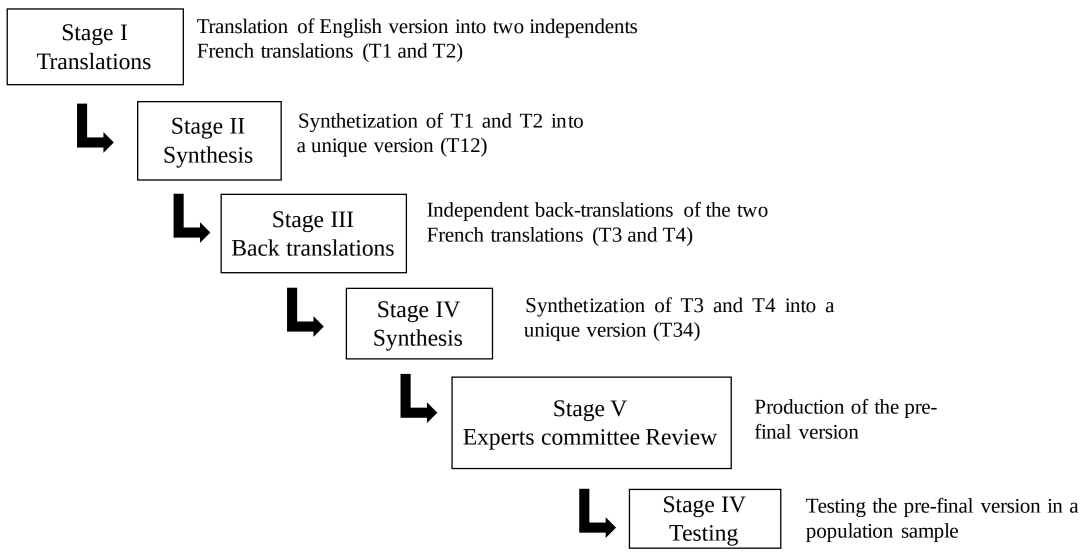


Figure 1: Schematic representation of the translation of the PRETIE-Q into a French version

Part B. Statistical analyses of the validity of the two subscales

After translating the PRETIE-Q into a French version (PRETIE-QF) and reporting no misunderstanding of any of the items, the psychometric qualities of the PRETIE-Q were assessed in a sample of 532 participants (mean$_{age}$ = 27,33 ± 10,6 years, mean$_{BMI}$ = 22,89 ± 3,95 kg.m-^{2}).

Participants characteristics

The first feature of our sample is the huge age range with the younger being 18 and the oldest 60 years of age. The second feature is the difference in terms of participants' "level of activity", as assessed by the Godin Questionnaire, with some participants reporting not practicing any physical activity (Godin score of 0), to the more physically active participant (Godin score of 208). Participants were recruited within the immediate social circles of the experimenters with some participants reporting being students of the University of Lille and others being friends or family members. Before the beginning of the study, each volunteer red an information letter and completed a written consent form. The study was approved by the Ethics Committee for behaviour human studies of the University of Lille, Human Sciences.

Firstly, we conducted the analysis on the all sample. Then, in order to observe if the two subscales are valid independently on individuals level of activity, we conducted statistical analyses in three independent sample determined as a function of participants' "level of activity". In such condition, we obtained 3 groups: an "Inactive" group with participants having a Godin score inferior or equal to 19 ($N = 165$, $mean_{age} = 28,64 \pm 11,17$ years, $mean_{BMI} = 23,24 \pm 4,26$ $kg.m^{-2}$), an "Active" group with participants having a Godin score superior to 19 and inferior or equal to 41 ($N = 203$, $mean_{age} = 28,31 \pm 11,62$ years, $mean_{BMI} = 23,06 \pm 4,32$ $kg.m^{-2}$), and an "Athletic" group with participants having a Godin score superior to 41 ($N = 163$, $mean_{age} = 24,80 \pm 7,99$ years, $mean_{BMI} = 22,36 \pm 2,99$ $kg.m^{-2}$). ANOVAs were conducted to assess a possible main effect of "level of activity" on Age, Body Mass Index (BMI), Educational Level and Repartition of men and women through groups. The characteristics of the sample are presented in the Table 1.

	“inactive” group (N=165)	“active” group (N = 203)	“athletic” group (N = 163)	Statistical analysis
Age (y)	28,65 (11,17)	28,31 (11,62)	24,80 (7,99)	F(2, 527) = 7.0254, p < 0.001
Body mass index (kg.m$^{-2)}$	23,24 (4,26)	23,05 (4,42)	22,35 (2,99)	F(2, 527) = 2.3289, p = 0.098
Educational Level (years)	3,03 (2,52)	2,97 (2,51)	3,16 (2,66)	F(2, 527) = 0.26118, p = 0.770
Repartition of men and women	Men: N= 47 Women: N= 118	Men: N= 68 Women: N= 134	Men: N= 76 Women: N= 90	khi-deux = 14.060, ddl = 3, p = 0,002

Table 1: Reports the descriptive results for Age (years), Body Mass Index (kg.m^{-2}), Educational Level (number of years after Baccalauréat) and Repartition of men and women as a function of “level of activity”.

Statistical analyses

Data were initially organized to check statistical assumption of items normality. Skewness and Kurtosis indices were used to assess respectively the degree of asymmetry and “peakedness” within the distribution of the different variables (Kline, 2011). The internal consistency reliability of the two subscales was examined in the entire sample (N = 532) and in each sub-sample (i.e., inactive, active and athletes). Cronbach’s alpha values of .70 or higher indicate acceptable internal consistency (Kline, 2010)

Results

Internal consistency

	Tolerance
Entire sample	
All items	$\alpha = 0.62$
Item 3 deleted	$\alpha = 0.70$
Item 3 and item 15 deleted	$\alpha = 0.76$
"Inactive" individuals	
All items	$\alpha = 0.58$
Item 3 deleted	$\alpha = 0.68$
Item 3 and item 15 deleted	$\alpha = 0.73$
"Active" individuals	
All items	$\alpha = 0.66$
Item 3 deleted	$\alpha = 0.73$
Item 3 and item 15 deleted	$\alpha = 0.78$
"Athletes" individuals	
All items	$\alpha = 0.54$
Item 3 deleted	$\alpha = 0.64$
Item 3 and item 15 deleted	$\alpha = 0.71$

Table 2: Reports the internal consistency of the Tolerance subscale as a function of individuals' "level of activity" and items deleted.

	Preference
Entire sample	
All items	$\alpha = 0.47$
"Inactive" individuals	
All items	$\alpha = 0.42$
"Active" individuals	
All items	$\alpha = 0.25$
Item 4 deleted	$\alpha = 0.44$
"Athletes" individuals	
All items	$\alpha = 0.49$
Item 6 deleted	$\alpha = 0.54$

Table 3: Reports the internal consistency of the Preference subscale as a function of individuals' "level of activity" and items deleted.

The results support a valid French-speaking version of the Tolerance subscale by deleting both item 3 and item 15 in all individuals with different “level of activity”. Nonetheless, the statistical analyses did not allow to valid the internal consistency of the Preference subscale. More specifically, no deletion of some of items would improve the psychometric quality of the Preference subscale both by conducting analyses in all individuals or in the three independent samples.

Test-retest reliability

Due to the difficulties to valid the internal consistency of the Preference subscale, the test-retest reliability was assessed only for the Tolerance subscale. Analyses were conducted in two samples. In the first sample (N = 38; 25 F, 13 M; $mean_{age}$ = 32,21 ± 10,12 years, $mean_{BMI}$ = 22,51 ± 4,41 kg.m-^{2}), individuals responded a second time after a 3-month delay. In the second sample (N = 63, 25 F, 13 M; $mean_{age}$ = 29,73 ± 10,29 years, $mean_{BMI}$ = 22,80 ± 3,73 kg.m-^{2}), individuals responded a second time after a 4-month delay. The 3-month test-retest reliability coefficient was 0.90 for the Tolerance subscale with deleting item 3 and item 15. The 4-month test-retest reliability coefficient was 0.90 for the Tolerance subscale with deleting item 3 and item 15.

Overall, our findings confirm strong internal consistency analyses for the Tolerance subscale of the French-speaking version of the PRETIE-Q.

III. Conclusion

The American College of Sports Medicine (2013), has recommended that individual differences in preference for and tolerance of exercise intensity should be considered in developing exercise prescriptions. Thus, the aim of the present study was to adapt the PRETIE-Q, a measure of these individual difference variables, for a use in the French-speaking population.

The translators and the back translator had only minor disagreements on the wording leading to the French-speaking version of PRETIE-Q. The psychometric evaluation of the French-speaking version of the PRETIE-Q showed that the Tolerance subscale was validated. More specifically, the internal consistency of the Tolerance subscale ranged from 0.71 to 0.78 as a function of the "level of activity" of individuals. Furthermore, the test-retest reliability was 0.90 at both 3-month and 4-month delays. However, the internal consistency of the Preference subscale was not sufficient to valid the construct of Preference for exercise intensity in our population. In fact, the internal consistency of the Preference subscale ranged from 0.42 to 0.54 as a function of the "level of activity" of individuals.

The difficulties encounter during the French validation lead to think about the reasons why the Preference subscale validation did not work so well. In fact, the translation was conducted in the best conditions. However, the way individuals perceive the proposition of each item still remain a problematic. More specifically, while the original version of the PRETIE-Q was validated mostly with American physically active undergraduate students, several differences have to be noted in comparison to our population. First, the population in which the questionnaire was originally validated was composed by students with age from 19.1 to 21.1 years old. Consequently, contrary to our population, the original validation was conducted only with young adults. In such a context, we can suppose that the Preference for exercise intensity can be mediated by the age of individuals. Second, undergraduate students were mostly physically active (66%). Consequently, contrary to our population, the original validation was conducted only with active young adults. In such a context, we can suppose that the Preference for exercise intensity can be mediated by the age of individuals. Third, the original version of the PRETIE-Q was validated in an American culture. Such validation can lead to results that may be not valid in European culture. More specifically, the culture in which individuals grow up may influence the way they perceive the world. Thus, the culture can also influence the way individuals define the Preference for exercise intensity construct. Furthermore, the American culture promote the practice of different physical exercise in comparison to European culture, such as American soccer or hockey. Thus, due to the different physical practice, American individuals may define differently their preference to low or high intense physical exercise in comparison to European population. For now, future research have to be conducted to assess such hypotheses.

Annexe A: French-speaking version of the PRETIE-Q

Questionnaire de l’Intensité Tolérée et Préférée

Merci de lire toutes les phrases et d’y répondre selon l’échelle de 1 à 5 qui vous est présentée ensuite. Il n’y a pas de bonnes ou de mauvaises réponses. Répondez le plus sincèrement possible en vous fiant à ce que vous ressentez. Faites attention à répondre à toutes les questions.

(**1 :** absolument pas d’accord**,** **2 :** pas d’accord, **3** : ni d’accord ni pas d’accord **4** : d’accord, **5** : absolument d’accord).

	1	2	3	4	5
Me sentir fatigué(e) pendant l’entraînement est mon signal pour ralentir ou m’arrêter					
Je préfère m’entraîner à basse intensité sur une longue durée plutôt qu’à haute intensité sur une courte durée					
Pendant l’entraînement, si mes muscles commencent à brûler de façon excessive ou si je commence à respirer très fortement, il est temps pour moi de ralentir					
Je préfère aller doucement pendant mon entraînement, même si cela implique de prendre plus de temps					
Pendant l’entraînement, j’essaie de continuer même lorsque je me sens épuisé(e)					
Je préfère avoir un entraînement court et intense qu’un entraînement long et de faible intensité					
J’ignore la sensation de fatigue pendant l’entraînement					
Quand je fais de l’exercice, je préfère généralement un rythme lent et continu					
Je préfère ralentir ou m’arrêter quand un entraînement devient trop dur					
Faire de l’exercice à une faible intensité ne me plaît pas du tout					
La fatigue est la dernière chose que je considère pour décider d’arrêter un entraînement, j’ai un objectif et je ne m’arrête que lorsque je l’atteins					
Quand je fais de l’exercice physique, je préfère des activités douces, réalisées à un rythme plutôt lent qui ne nécessitent pas un épuisement					
Généralement, quand mes muscles commencent à brûler pendant un exercice, je ralentis un peu					
Plus les exercices physiques sont rapides et intenses, mieux je me sens					
Je vais toujours au-delà de l’inconfort musculaire et de la fatigue quand je m’entraîne					
Les exercices de faible intensité sont ennuyeux					

What's next?

In Study I, we reported data indicating that the concept of Tolerance of exercise intensity has a good construct and thus, is *valid* in French-speaking European individuals. More importantly, the validation was confirmed in the three samples of participants who were characterised by different levels of self-reported weekly physical practice. Nonetheless, the statistical analyses did not allow to confirm such good construct in the Preference subscale both when conducting the analyses in all subjects and in the three independent samples. Hence, in either studies I decided to use only the Tolerance subscale to assess how individuals' psychological characteristics may explain one's experience of physical exercise.

To better understand the reasons why the Preference subscale was not valid in our sample, we decided to assess how individuals' culture may influence the validation of the Preference subscale. The choice of the Quebecer population is that they are individuals living in an American culture while speaking both French and English. The validation procedure of the French-speaking version of the PRETIE-Q is an ongoing project conducted in collaboration with Professor Louis Bherer and Dr. Laurence Desjardin-Crépeaux at the University of Quebec Montréal (UQAM).

In the context of the necessity to constantly increase our understanding about the physical exercise – cognition and physical exercise – adherence relationships, the Study II deals with the cognitive definition of physical exercise. More specifically, in the context of difficulties that remain when understanding these relationships, it was suggested that assessing the cognitive load of physical exercise may be a promising way (Pesce, 2016; Burzynska et al., 2017; Müller et al., 2017). Nevertheless, even if such consideration allows to combine the field of cognitive psychology to the field of sport psychology, the methodological procedure revealing that physical exercise can be defined from a cognitive standpoint remains to be developed.

Study II presents a dual-task paradigm that aimed to show that physically exercise requires cognitive resources. Furthermore, we report how the way one perceives the difficulty of a physical exercise may be predicted by both the physical and the cognitive loads of the exercise. Finally, we will demonstrate that the complexity of the task as well as the individual’s tolerance influence the cognitive resources required to handle the physical exercise and adjust motor output.

Study II

The Cognitive Load of Physical Exercise: Effects of Task Complexity and Tolerance to effort.

In preparation for submission in Special Issue of Neuropsychologia called Cognitive effort

Mauraine CARLIER[1], & Yvonne DELEVOYE-TURRELL[1]*

[1]SCALab, UMR CNRS 9193, Department of psychology, University of Lille, Lille, France

***** Corresponding author
E-mail: yvonne.delevoye@univ-lille3.fr (YD)
These authors contributed equally to this work.

HIGHLIGHTS

1. The perception of effort is composed of both a physical and a cognitive component.
2. Dancing is perceived as more cognitively and more physically demanding than Cycling or Stepping.
3. The cognitive cost of a physical activity is greater for Low than High Tolerant individuals.
4. Tolerance modulates the perception of effort and the affective states experienced during practice.
5. The desire to re-exercise depends on the affective states during practice and the heart rate frequency measured during recovery.

I. Introduction

Physical exercise is a type of motor activity that requires organisation, planning and sequencing of bodily movements that are performed in the aim to improve and/or maintain one or more components of physical fitness (American College of Sports Medicine et al., 2010). Hence, exercising consists in the task of regularly producing series of coordinated contractions of skeletal muscles, which results in a substantial increase in caloric requirements compared to the energy expenditure measured at rest (Caspersen et al., 1985). Classically, physical exercise is defined as a function of the physical energetic expenditure required to perform the task (i.e., Metabolic Equivalent of Task – METs). Nonetheless, since recently, in addition to defining physical exercise through the concepts of mode of progress (i.e., constant or incremental load), intensity (i.e., low, moderate, vigorous), duration (i.e., seconds, minutes, hours) and the metabolism supplying the muscles energy (i.e., aerobic and anaerobic metabolism - Audiffren, 2009), physical exercise is starting to be considered through the concept of *cognitive load*, i.e., the amount of cognitive resources required to perform the motor task. More specifically, it was suggested that the way individuals can cognitively benefit from physical exercise may depend on the cognitive challenges occurring the planning and the execution of the motor task (Pesce, 2016; Burzynska et al., 2017; Müller et al., 2017). Nevertheless, direct observation of the cognitive load of physical exercise has yet to be reported. Thus, the aim of this original research was to develop a dual task paradigm for an ecological fitness task in order to reveal that physical exercise requires cognitive resources.

Human Cognition is defined as a system of the mental processes associated with attention, perception, thinking, learning, and memory enabling individuals to adapt their behaviour in a given context (Loring & Meador, 1999). During the course of phylogenetical and developmental evolutions, human cognitive was elaborated to guide individuals in the efficient control and self-regulation of their motor behaviour (Cisek & Kalaska, 2010; Koziol et al., 2011; Koziol, & Lutz, 2013).

In the field of physical exercise, it was suggested that cognitive process may be required to help individuals in the self-regulation of their effort (Audiffren and André, 2015; Audiffren, 2016). More specifically, the corollary discharge theory suggest that during the performance of a motor task, the perception of tolerable discomfort and effort will depend on the integration between (1) a predicted sensory information sent directly from the motor to the sensory areas of the brain and (2) an actual sensory information received by the sensory areas of the brain directly from the body (Abbiss, Peiffer, Meeusen, & Skorski, 2015). In a case of a match between the predicted and the actual effort, the motor task is performed at an intensity of difficulty that was expected. However, in the case of a mismatch, the discrepancy that exist between the predicted and the actual effort needs to a re-adjustment of the motor behaviour; leading individuals to perceived the motor production as more effortful than it was expected. Thus, the way one experiences the effort of a physical exercise may depend on the difficulty intituled in the preparation, execution and self-regulation of the motor task.

Due to the challenges that may occur in the planning and the execution of the task, the way one experiences the effort of a physical exercise may also depend on the motor complexity of the motor task. Hence, while some will require a minimum amount of cognitive resources to be performed, others will need to be supported by a high amount of cognitive resources (Burzynska et al., 2017; Müller et al., 2017). The point of transition between predominantly aerobic energy production and anaerobic energy production (Ventilatory Threshold - VT) is an intensity of practice at which non-efficiently predictive process may lead to highly threatening consequences.

More specifically, at this intensity due to the involvement of the anaerobic metabolism to support the muscle energy production, the homeostasis state is fragile and risks to be lost as soon as the VT threshold is crossed. Hence, in order to be able to perform the task throughout time, individuals have to efficiently predict the consequences of their motor behaviour without error. If they do not, a possible greater threat of the homeostasis will emerge due to the necessity to allocate cognitive resources to re-adjust the motor output whereas resources are needed to maintain homeostasis and stability within the system. In consequence, non-efficient motor prediction abilities will lead individuals to experience sooner and more often negative states than those possessing the required cognitive resources to handle the task. Furthermore, while some individuals will possess enough cognitive resources to tolerate pain or discomfort during the performance of a motor task, especially when the homeostasis is threatened, some others will be able tolerate motor behaviour performed only at an intensity that require minimum of cognitive resources to handle physical discomfort or pain.

The objective of this original experimental research was to reveal that *physical exercise can be defined from the cognitive load emerging from the necessity to planning and adjusting motor behaviour*. More specifically, through the conduction of a self-paced protocol during which we asked individuals to perform a “somewhat difficult” motor task, i.e., the level of effort at which VT appears (Feriche et al., 1998; Stojiljković et al., 2004), we revealed that physical exercise can be defined from the cognitive resources required to perform the task. Furthermore, we also tried to reveal that the way one perceives the difficulty of a physical exercise depend on both the motor task complexity and individuals’ ability to tolerate difficulties.

II. METHOD

a) Participants

A total of 58 subjects volunteered to take part in the study, 17 men and 41 women (M_{age}= 21.96 ± 5.18 years, M_{BMI}= 23.88 ± 9.63 kg.m-2). Participants were allocated to three independent conditions (Cycling vs. Stepping vs. Dancing) and two independent groups (Low vs. High Tolerant individuals). All subjects obtained a medical certificate from their medical physicians before being include in the study. Before the beginning of the study, each volunteer read an information letter and completed a written consent form. The study was approved by the Ethics Committee for behaviour human studies of the University of Lille. Participants were asked not to participate in any physical training 48 hours before their inclusion.

b) Materials and Procedure

After reading and completing the consent form, a heart rate monitor (Polar Team[2] - Polar Electro Oy, Kempele, Finlande) was fitted to the participants' chest and heart rate was recorded during 15 minutes at rest, and throughout the experimental session. After measuring mean heart rate at rest, participants were asked to complete a series of questionnaires in order to obtain socio-demographic data. A testing diagram is presented in Fig 1 to illustrate the experimental design.

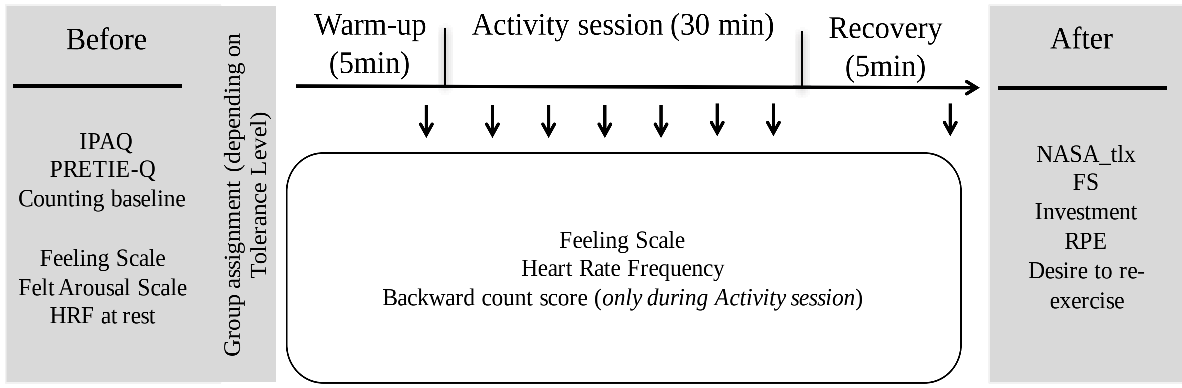


Figure 1: Testing diagram to specify the experimental design that was used in the present study. The different measures taken before, during and after are specified.

Self-reported physical activity level assessment

The IPAQ (International Physical Activity Questionnaire) was used to assess the amount of physical activity practiced by the participants (Craig et al., 2003). The quantity of physical activity practiced by each participant was calculated by considering the intensity of the reported physical activity sessions (expressed in METs – Metabolic Equivalent of Task – for 3 different categories: low vs. moderate vs. vigorous) as a function of duration (time in minutes) and of the number of days declared per week (METs-minute/week). The feature of this questionnaire is to consider the overall self-reported physical activity level (including daily activities) and not only the physical activity practiced during leisure sports time. Four different measures were obtained: (1) the Total Physical Activity score, which contains the total amount of physical activity practiced (e.g., METs-minute/week$_{_Low}$, METs-minute/week$_{_Moderate}$ and METs-minute/week$_{_Vigorous}$), (2) the Total Low Physical Activity score, (3) the Total Moderate Physical Activity score and (4) the Total Vigorous Physical Activity score.

Preference for and Tolerance to the Intensity of Exercise assessment

The PRETIE-Q was used to assess the variables of preference for and tolerance to exercise intensity. The eight-item Tolerance scale contained four items that targeted high exercise tolerance (e.g., ‘‘I always push through muscle soreness and fatigue when working out’’) and four that targeted low exercise tolerance (e.g., ‘‘During exercise, if my muscles begin to burn excessively or if I find myself breathing very hard, it is time for me to ease off’’). Each item was composed of a 5-point response scale (1 = ‘‘I totally disagree’’; 2 = ‘‘I disagree’’; 3 = ‘‘Neither agree or disagree’’; 4 = ‘‘I agree’’; 5 = ‘‘I strongly agree’’). A high score of tolerance to exercise corresponds to a high capacity to pursue the physical activity although it becomes uncomfortable or unpleasant (Ekkekakis et al., 2005). To obtain two contrasting groups, a median tolerance score was calculated across all groups. Participants with scores lower than the median (18) were considered as Low Tolerant; individuals with scores greater than the median were classified as High Tolerant. After assessing tolerance level, participants were assigned to three independent conditions: a Cycling Condition, a Stepping Condition or a Dancing Condition. In the Cycling Condition, there were 13 Low Tolerant individuals and 5 High Tolerant individuals, in the Stepping Condition there were 10 Low Tolerant individuals and 10 High Tolerant individuals, and in the Dancing Condition there were 9 Low Tolerant individuals and 11 High Tolerant individuals. Due to problems occurring during the Cycling Condition, the repartition of Low and High Tolerant individuals were not equal in comparison to Stepping and Dancing Conditions.

Assessing the load of executing a physical activity

Global load

<u>Investment assessment:</u> Participants were asked, 10 minutes after the end of the session, how much they felt cognitively and physically involved in the activity. The bipolar scale ranged from

-4 to +4. Anchors are provided at zero and at all even integers (-4 = not at all; -2 = hardly; 0 = neutral; +2 = a lot; +4 = to a large degree).

Perception of effort assessment: the Ratings of Perceived Exertion was used 10 minutes after the end of the condition to verify that participants considered having done a physically and cognitively “somewhat difficult” physical activity throughout the session (RPE 13 on the 6-20 Borg Scale ; Borg, 1998).

Physical load

Subjective measure: the subjective perception of the physical load was determined using the French version of the NASA Task Load Index (NASA_tlx; Cegarra, & Morgado, 2009). Participants were asked to quantify the load of their task only in the dual-task condition (backward counting while exercising).

Objective measure: a heart rate monitor (Polar Team[2]—Polar Electro Oy, Kempele, Finlande) was fitted to the participants’ chest and heart rate was recorded the session.

Cognitive load

Subjective measure: the cognitive demand scale of the NASA-tlx questionnaire was used to assess to subjective perception of the cognitive load of the physical activities.

Objective measure: in order to assess the cognitive load of each physical activity (Cycling, Stepping and Dancing), participants were asked to perform another task during the 30’ of the practice of the moderate physical activity (i.e., dual task paradigm). The secondary task consisted in a backward counting task. The objective of participants was to count from 7 to 7 in a backward way from a clearly defined number, every 3 minutes for 1 minute. In order to obtain homogeneous groups, a preliminary evaluation of participants' abilities to count was carried out before the inclusion in each condition. Thus, one measure was obtained before starting the physical activity session, 8 during each moderate physical activity bout (at 1', 5', 9', 13', 17', 21', 25' and 29'). During the warm-up and recovery periods, participants were asked to perform only the physical activity. Hence, for objectively revealing the cognitive cost of each physical activity, the percentage of correct counts per minute was the dependent variable (PC).

c) Identifying the individuals' affective states through physical activities

The Feeling Scale (Hardy & Rejeski, 1989) was used to assess the changes in the valence of the affective states (pleasure / displeasure). This scale consists in a 11-point, single-item, bipolar scale, used for the assessment of the valence component of affective responses during exercise. The scale ranges from −5 to +5. Anchors are provided at zero, and at all odd integers (+5 = very good; +3 = good; +1 = fairly good; 0 = neutral; −1 = fairly bad; −3 = bad; −5 = very bad).

d) Assessing the desire to re-exercise

Such as the experience of a physical activity impacts/influences a future practice, the desire to re-exercise the actual physical activity was achieved using a 9-point bipolar scale. This scale was created to get a feel of how much practitioners wanted to exercise again, 10 min after finishing to exercise. The scale ranged from -4 to +4. Anchors are provided at zero and at all even integers (-4 = not at all; -2 = not really; 0 = neutral; +2 = a lot; +4 = to a large degree).

e) Conditions

Following the scores obtained in the PRETIE-Q questionnaire, participants were evenly assigned to three independent conditions: a cycling condition, a stepping condition, and a dancing condition. All of the conditions were performed in silence. During the exercise session, participants performed 40 minutes of physical activity. Three phases were proposed: the warm-up (5 minutes), the physical activity (30 minutes), and the recovery periods (5 minutes) – following criterion described in ACSM (2010).

For all three conditions, changes in the affective states were assessed using the Feeling Scale (FS). The FS was administered before warm up, after warm-up, and every 5 minutes during the practice phase. Thus, nine periods were identified: one before warm-up (0'), one after warm-up (5’), six during the test (10', 15', 20', 25', 30’, 35’), and one after recovery (40'). For all participants, debrief was systematically conducted after the session to explain the aims and the construct of the study.

Both in the cycling and the stepping conditions, a picture of a path through a forest was projected on a screen (195 cm x 280 cm) placed 250 cm in front of the participants. In the dancing condition, participants were instructed to follow the dynamic steps presented in front of them by an avatar using the Domyos Interactive System (Decathlon). Pleasant light was also proposed to optimize the pleasant experience of the physical activity (Shaulov & Lufi, 2009). During the warm-up phase, participants were asked to pedal, to step and to dance at a speed that would allow them to warm-up and to become familiar with the material. During the physical activity (30 min), participants were required to perform the physical exercise in order to feel the session as "somewhat difficult" on the Borg RPE scale (RPE 13 on the 6-20 Borg Scale). As different definitions can be considered when asking individuals to select the score of perceived effort (Abbiss et al., 2015), in this study, the effort was defined to participants as “the amount of mental or physical energy being given to [the] task” (Abbiss et al., 2015). Thus, during the physical activity period, participants had to perform a physical activity perceived as physically and cognitively “somewhat difficult”. The heart rate frequency (HRF) was measured every minute.

Nevertheless, for the statistical analyses, HRF data were resampled at one sample every 5 minutes.

f) Statistical analyses

ANOVAs were conducted to reveal main effects of Tolerance Level (High versus Low Tolerant) and Conditions (Cycling, Stepping, Dancing) on general demographics. ANCOVAs were conducted to reveal main effects of Condition and Tolerance Level while controlling for the self-reported physical activity level. A series of ANCOVAs were conducted on (1) the mean scores of the perception of exertion scale, (2) the sense of investment felt in the three physical activity conditions, (3) the desire to re-exercise and on (4) each of the questions specified in the NASA_tlx. Mixed Model ANCOVAs were conducted to determine effects of Condition {3}, Tolerance Level {2} and Assessment Time {8} on the Feeling Scale (FS), on the Heart Rate Frequency (HRF) and on the Percentage of correct counts (PC) while controlling for the self-reported physical activity level. For the FS, HRF and PC variables, baseline values were systematically included within the statistical model as covariates. Throughout these analyses, partial eta squares (η^2_p) were calculated to report the effect sizes. Bonferroni-adjusted pairwise comparisons were used when required for the post-hoc analyses.

In a second series of analyses, regression analyses were conducted (1) to reveal the part of both cognitive and physical perceived demands when assessing the Ratings of Perceived Exertion (using the 6-20 Borg Scale) and (2) to explain the desire to re-exercise as a function of the individuals' subjective measures conducted through the experimental protocol. Before conducting the regression analysis, we performed correlational analysis – using Pearson's correlation coefficient - between factors. Conducting an analysis of the correlations allowed us to choose the regression factors by minimizing at best the overlap between factors. Then, the regression analysis was conducted from a descendant perspective by considering every factor and subtracting those playing a none significant role within the regression model.

III. Results

a) Group demographics

The participants that were allocated to the three independent Conditions (Cycling vs. Stepping vs. Dancing) did not differ in Age (F(2,55) = 0.188, p = 0.829), in the number of men and women within groups (khi-deux = 0,156, ddl = 2, p = 0,561), in Body Mass Index (F(2,55) = 0.856, p = 0.431), in the number of Low and High Tolerant individuals (F(2,55) = 1.589, p = 0.213) and in the overall Tolerance scores (F(2,55) = 1.025, p = 0.366). A main Condition effect on Educational Level was revealed (F(2,55) = 4.666, p = 0.014, η^2 = 0.15) with individuals in the Cycling Condition having performed less university studies ($M_{Cycling}$ = 2.25, SD = 1.64) than those in the Dancing Condition ($M_{Dancing}$ = 3.31, SD = 1.30) (p = 0.011). A main Condition effect was observed on some of the IPAQ dimensions. More specifically, a main effect was revealed on Total Physical Activity (F(2,55) = 3.248; p = 0.046, η^2 = 0.11), Total Low (F(2,55) = 5.221; p = 0.008, η^2 = 0.16) and Total Moderate scores (F(2,55) = 3.871; p = 0.027, η^2 = 0.12). Nevertheless, the Bonferroni post-hoc analyses did not allow to obtain statistical differences between conditions. No main Condition effects were revealed on Total Vigorous score (F(2,55) = 0.339; p = 0.713). Detailed results are presented in the Table 1.

The participants who were allocated to two independent groups (Low vs. High Tolerance groups) did not differ in Age (F(1,56) = 1.736, p = 0.193), Body Mass Index (F(1,56) = 2.426, p = 0.125), Educational Level (F(1,52) = 1,643, p = 0.206), Total Low IPAQ score (F(1,56) = 1.282; p =

0.262) and Total Moderate IPAQ score ($F(1,56) = 1.181$; $p = 0.282$). An effect of the Tolerance Level was revealed on the Repartition of men and women within groups (khi-deux = 3.842, ddl = 1, p = 0,049) with women having lower Tolerance Level ($M_{women} = 18.00$, $SD = 5.04$) compared to men ($M_{men} = 21.59$, $SD = 4.73$). A main effect of Tolerance Level was revealed on Total Vigorous IPAQ score ($F(1,56) = 7.342$; $p = 0.009$, $\eta^2 = 0.12$) with Low Tolerant individuals producing less weekly vigorous physical activities ($M_{Low} = 590.00$, $SD = 890.03$) compared to High Tolerant individuals ($M_{High} = 1764.62$, $SD = 2248.48$). A main effect of the Tolerance Level was also revealed on Total Physical Activity IPAQ score ($F(1,56) = 4.623$; $p = 0.035$, $\eta^2 = 0.08$) with Low Tolerant individuals producing less weekly total physical activities ($M_{Low} = 2366.88$, $SD = 2191.50$) compared to High Tolerant individuals ($M_{High} = 4304.36$, $SD = 4484.76$). Detailed results are presented in the Table 2.

	Cycling Condition (N=18)	Stepping Condition (N = 20)	Dancing Condition (N = 20)	Statistical analysis
Age (y)	21.40 (2.44)	21.95 (3.83)	22.38 (4.03)	F(2,55) = 0.188, p = 0.829
Body mass index (kg.m^{-2})	21.99 (10.53)	23.44 (8.62)	25.02 (9.79)	F(2,53) = 1.508, p = 0.231
Educational Level (years)	2.25 (1.16)	2.95 (1.10)	3.31 (1.30)*	F(2,55) = 4.666, p = 0.014, η^2 = 0.15
Tolerance Score	17.78 (4.86)	20.25 (5.35)	19.45 (5.33)	F(2,55) = 1.025, p = 0.366
Repartition of men and women	Men : N= 8 Women : N= 12	Men: N= 5 Women : N= 15	Men: N= 3 Women : N= 13	(khi-deux = 0,156, ddl = 2, p = 0,561)
Repartition of Low and High Tolerant to exercise	Low : N= 13 High : N= 5	Low : N= 10 High : N= 10	Low : N= 9 High : N= 11	F(2,55) = 1.589, p = 0.213
Total Low Physical Activity (METs-minutes/week)	2198.17 (2018.16)	838.20 (484.19)*	1084.22 (1246.03)*	F(2,55) = 5.221; p = 0.008, η^2 = 0.16
Total Moderate Physical Activity (METs-minutes/week)	1360.00 (1791.54)	554.40 (387.98)	465.50 (601.24)*	F(2,55) = 3.871; p = 0.027, η^2 = 0.12
Total Vigorous Physical Activity (METs-minutes/week)	1366.67 (2558.58)	1110.00 (975.65)	898.00 (1437.92)	F(2,55) = 0.339; p = 0.713
Total Physical Activity Practiced (METs-minutes/week)	4924.83 (5134.49)	2502.60 (1255.06)	2447.72 (2837.10)	F(2,55) = 3.248; p = 0.046, η^2 = 0.11

Table 1: Demographics and Fitness level. Descriptive results for Age (years), Body Mass Index (kg.m-2), Educational Level (number of years after French Baccalauréat), Tolerance Score, Repartition of men and women, Repartition of Low and High Tolerant and the quantitative amount of physical activity practiced (METs: Metabolic Equivalents - a useful, convenient and standardized way to describe the absolute intensity of a variety of physical activities - ACSM, 2014), as a function of group (* differing from Cycling Condition)

	Low Tolerant individuals (N = 32)	High Tolerant individuals (N = 26)	Statistical analysis
Age (y)	21.44 (3.33)	22.62 (3.45)	F(1,56) = 1.736, p = 0.193
Body mass index ($kg.m^{-2}$)	22.44(9.48)	26.04 (9.55)	F(1,56) = 2.426, p = 0.125
Educational Level (years)	3.17 (1.44)	2.67 (1.40)	F(1,52) = 1,643, p = 0.206
Repartition of men and women	Men : N= 6 Women : N= 16	Men : N= 11 Women : N= 15	khi-deux = 3.842, ddl = 1, p = 0,049
Total Low Physical Activity (METs-minutes/week)	1148.81 (1319.31)	1586.67 (6138.00)*	F(1,56) = 1.282; p = 0.262
Total Moderate Physical Activity (METs-minutes/week)	628.06 (694.02)	953.08 (6240.00)	F(1,56) = 1.181; p = 0.282
Total Vigorous Physical Activity (METs-minutes/week)	590.00 (890.03)	1764.62 (10560.00)	F(1,56) = 7.342; p = 0.009, η^2 = 0.12
Total Physical Activity Practiced (METs-minutes/week)	2366.88 (2191.50)	4304.36 (15889.00)	F(1,56) = 4.623; p = 0.035, η^2 = 0.08

Table 2: Demographics and Fitness level. Descriptive results for Age (years), Body Mass Index (kg.m-2), Educational Level (number of years after Baccalauréat), Repartition of men and women, as well as IPAQ scores (METs: Metabolic Equivalents - a useful, convenient and standardized way to describe the absolute intensity of a variety of physical activities - ACSM, 2014) as a function of Tolerance Level.

b) Assessing the load of physical activities

Global load

Participants' investment. Neither a Condition main effect ($F(2,50) = 1.799$, $p = 0.176$), nor a Tolerance Level main effect were revealed ($F(1,50) = 2.477$, $p = 0.122$). However, the interaction Conditions*Tolerance Level was observed ($F(2,50) = 3.473$, $p = 0.039$, $\eta^2 = 0.12$) with, in the Stepping Condition, Low Tolerant individuals being less invested ($M_{Low} = 1.10$, $SD = 1.37$) in comparison to the High Tolerant individuals ($M_{High} = 2.70$, $SD = 0.82$) ($p = 0.032$) (Fig 2-*left*).

Perception of effort. A main effect of Condition was revealed ($F(2,50) = 11.282$, $p < 0.001$, $\eta^2 = 0.31$). More specifically, the Stepping Condition was perceived as less effortful ($M_{Stepping} = 11.00$, $SD = 2.10$) than both the Cycling ($M_{Cycling} = 13.17$, $SD = 1.20$) ($p < 0.001$) and the Dancing condition ($M_{Dancing} = 13.32$, $SD = 1.46$) ($p < 0.001$) (Fig. 2-*right*). A main effect of Tolerance Level was revealed ($F(1,50) = 4.793$, $p = 0.033$, $\eta^2 = 0.09$) with Low Tolerant individuals overall perceiving the sessions as more effortful ($M_{Low} = 12.95$, $SD = 1.98$) than the High Tolerant individuals ($M_{High} = 11.88$, $SD = 1.77$) (Fig. 2-*right*). No interaction between Condition and Tolerance Level was observed ($F(2,50) = 0.029$, $p = 0.971$).

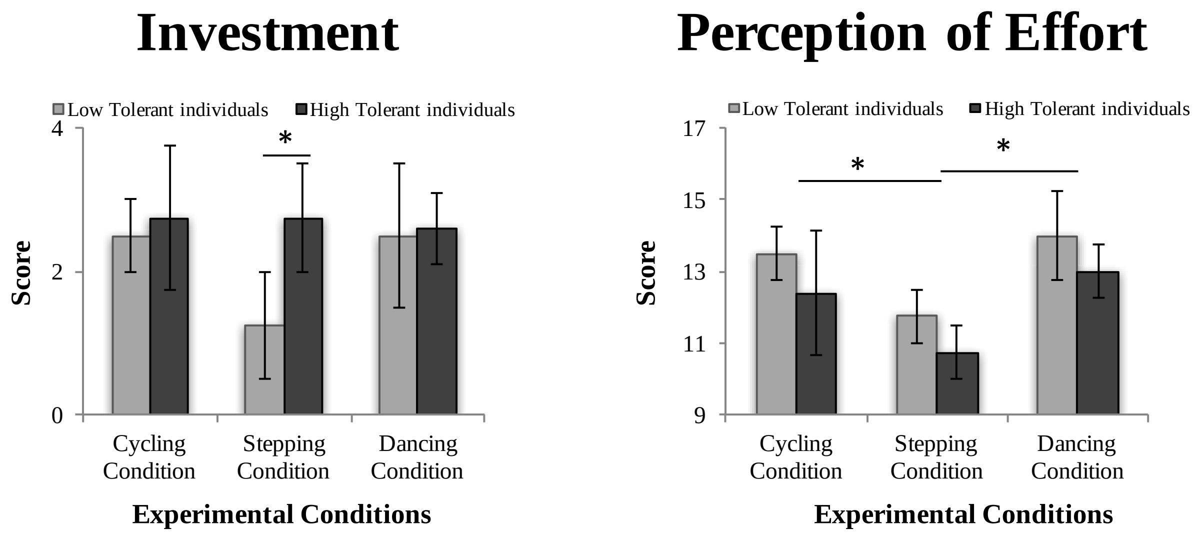
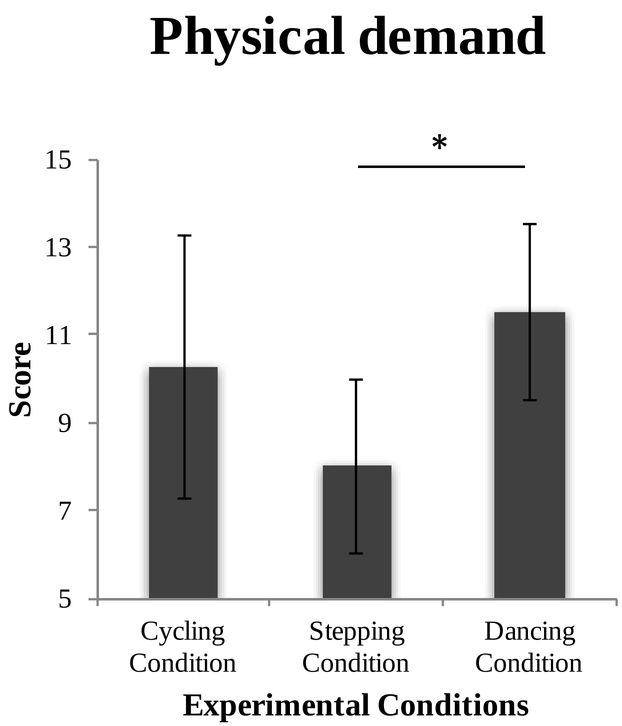


Figure 2: Scores of investment (*left*) and perception of effort (*right*) as a function of the condition: Cycling, Stepping and Dancing in Low Tolerant individuals (*grey*) and High Tolerant individuals (*black*). Error bars illustrate the confidence intervals 95% around the mean (* $p < 0.05$).

c) Physical load

Subjective measure. A main effect of Condition was revealed ($F(2,51) = 3.211$, $p = 0.048$, $\eta^2 = 0.11$) (Fig. 3-*left*). The Dancing Condition was perceived as more physically demanding ($M_{Dancing} = 15.95$, $SD = 2.50$) than the Stepping Condition ($M_{Stepping} = 12.50$, $SD = 4.35$) ($p = 0.047$). No main effect of the Tolerance Level was revealed ($F(1,51) = 2.193$, $p = 0.144$). The interaction Condition*Tolerance Level did not reach significance ($F(2,51) = 0.506$, $p = 0.606$).



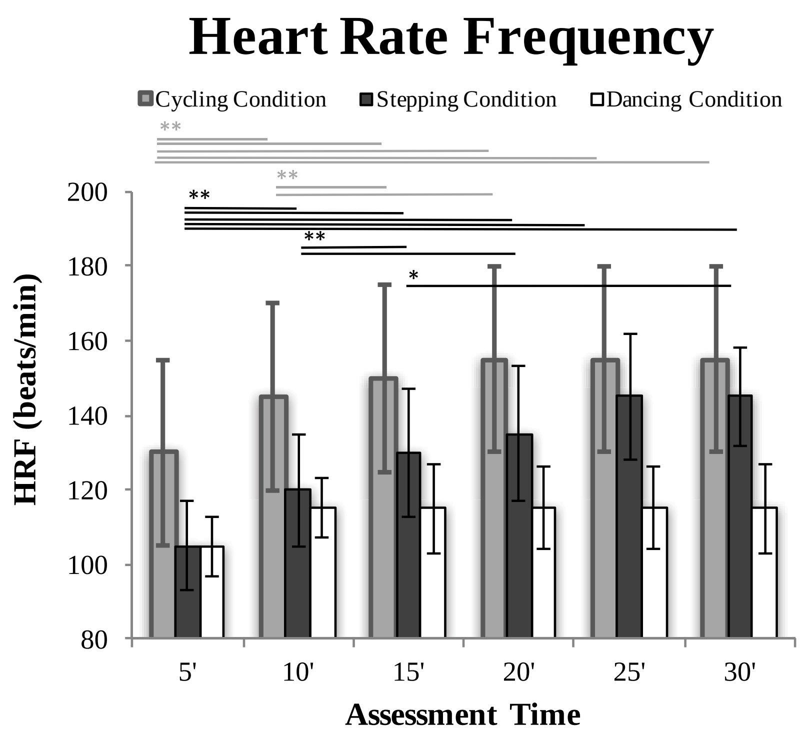


Figure 3: Scores of Physical demand (*left*) and Variations in Heart Rate Frequency (*right*) as a function of the condition: Cycling, Stepping and Dancing. Error bars illustrate the confidence intervals 95% around the mean (*p < 0.05 and **p < 0.01).

Objective measure.

Baseline measure. Neither a main effect of the Condition ($F(2,36) = 1.761$, $p = 0.186$) nor a main effect of the Tolerance Level were revealed ($F(1,36) = 1.054$, $p = 0.311$). The interaction Condition*Tolerance Level did not reach significance ($F(2,36) = 0.827$, $p = 0.445$). Thus, before starting the physical activity, the HRF in Low and High Tolerant individuals were similar across conditions.

Warm-up measures. Neither a main effect of the Condition nor a main effect of the Tolerance Level were revealed. The interaction Condition*Tolerance Level did not reach significance (Table 3). Thus, the Heart Rate Frequency was similar in both Low and High Tolerant individuals across conditions after the warm-up period.

Practice measures. The main effect of Condition reached significant tendency ($F(2,35) = 3.061$ $p = 0.059$). No main effect of the Tolerance Level was observed ($F(1,35) = 0.016$, $p = 0.901$). The interaction Condition*Tolerance Level did not reach significance ($F(2,35) = 2.249$, $p = 0.121$). No main effect of the Assessment Time was revealed ($F(5,175) = 0.097$, $p = 0.993$). Nevertheless, the interaction Assessment Time*Conditions was significant ($F(10,175) = 2.981$, $p = 0.002$, $\eta^2 = 0.15$). More specifically, an increase of the HRF was revealed in the Cycling and Stepping Conditions but not in the Dancing condition (Fig. 3-*right*). The interaction between Assessment Time and Tolerance Level did not reach significance ($F(5,175) = 0.834$, $p = 0.526$). The triple interaction Assessment Time*Condition*Tolerance Level reached significance ($F(10, 175) = 2.680$, $p = 0.005$, $\eta^2 = 0.13$). Detailed results are presented in Fig. 4-*left*, Fig. 4-*middle* and Fig. 4-*right*.

Recovery measures. A main effect of Condition was revealed ($F(2,35) = 5.326$, $p = 0.009$, $\eta^2 = 0.23$). More specifically, the overall Heart Rate Frequency was smaller in the Dancing Condition ($M_{Dancing} = 119.91$, $SD = 27.55$) compared to both the Cycling ($M_{Cycling} = 146.19$, $SD = 19.07$) ($p = 0.033$) and the Stepping Condition ($M_{Stepping} = 141.98$, $SD = 23.43$) ($p = 0.041$). No other main effects or interaction were found (Table 3).

	Warm up Period				Physical activity at RPE 13				Recovery Period			
	F	***df***	***p***	η^2_p	***F***	***df***	***p***	η^2_p	***F***	***df***	***p***	η^2_p
Main effects												
Feeling Scale												
Condition effect	0.094	2,50	0.911	0.00	0.066	2,50	0.937	0.00	0.399	2,50	0.673	0.02
Tolerance effect	0.001	1,50	0.973	0.00	11.030	1,50	**0.002**	0.19	4.743	1,50	**0.034**	0.09
Assessment Time	--	--	--	--	1.216	5,250	0.302	0.02	--	--	--	--
Heart Rate Frequency												
Condition effect	0.306	2,35	0.739	0.02	3.061	2,35	0.059	0.15	5.326	2,35	**0.009**	0.23
Tolerance effect	1.237	1,35	0.274	0.03	0.016	1,35	0.901	0.00	0.024	1,35	0.877	0.00
Assessment Time	1.008	4,140	0.406	0.03	0.097	5,175	0.993	0.00	0.458	4,140	0.766	0.02
Backward counts												
Condition effect	--	--	--	--	2.701	1,50	0.077	0.10	--	--	--	--
Tolerance effect	--	--	--	--	5.499	2,50	0.203	0.03	--	--	--	--
Assessment Time	--	--	--	--	1.648	7,350	0.121	0.03	--	--	--	--
Interactions effects												
Feeling Scale												
Condition*Tolerance	0.673	2,50	0.515	0.03	0.763	2,50	0.472	0.03	0.668	2,50	0.517	0.02
Assessment Time* Condition	--	--	--	--	0.881	10,250	0.552	0.03	--	--	--	--
Assessment Time*Tolerance	--	--	--	--	4.477	5,250	**< 0.001**	0.08	--	--	--	--
Assessment Time* Condition*Tolerance	--	--	--	--	1.588	10,250	0.110	0.06	--	--	--	--
Heart Rate Frequency												
Condition*Tolerance	1.021	2,35	0.371	0.06	2.249	2,35	0.121	0.11	1.014	2,35	0.373	0.05
Assessment Time*Condition	0.921	8,140	0.501	0.05	2.981	10,175	**0.002**	0.15	0.332	8,140	0.952	0.02
Assessment Time*Tolerance	1.189	4,140	0.318	0.04	0.834	5,175	0.526	0.02	0.469	4,140	0.758	0.01
Assessment Time*Condition*Tolerance	0.729	8,140	0.666	0.03	2.680	10,175	**0.005**	0.13	0.978	8,140	0.456	0.05
Backward counts												
Condition*Tolerance	--	--	--	--	5.499	2,50	**0.007**	0.18	--	--	--	--
Assessment Time*Condition	--	--	--	--	1.053	14,350	0.399	0.04	--	--	--	--
Assessment Time*Tolerance	--	--	--	--	0.968	7,350	0.454	0.02	--	--	--	--
Assessment Time*Condition*Tolerance	--	--	--	--	0.879	14,350	0.582	0.03	--	--	--	--

Table 3: Overall statistical results for the main effects and the interactions on Feeling Scale, Heart Rate Frequency and Backward counts as a function of Assessment time, Condition and Tolerance

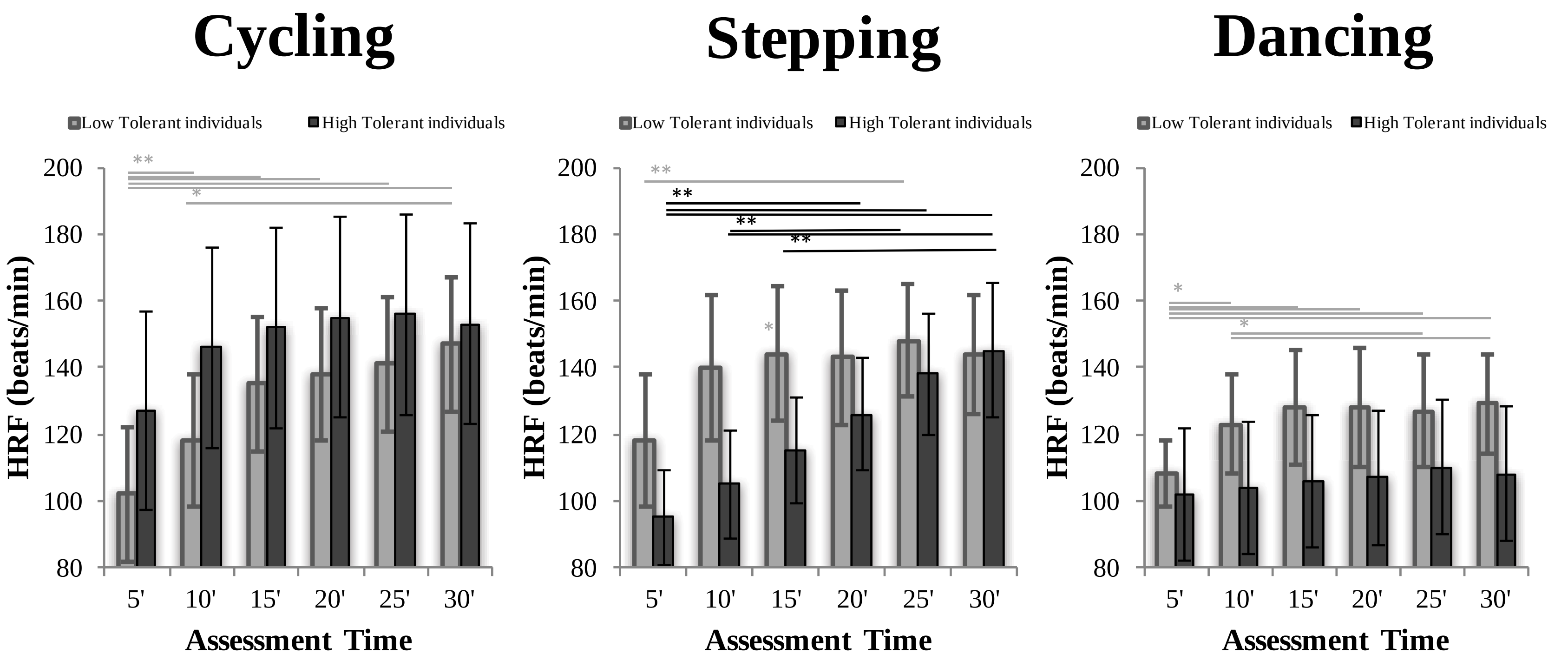


Figure 4: Variations in Heart Rate Frequency as a function of the condition: Cycling (*left*), Stepping (*middle*) and Dancing (*right*) in Low Tolerant individuals (grey) and in High Tolerant individuals (black). Error bars illustrate the confidence intervals 95% around the mean (*p < 0.05 and **p < 0.01).

d) Cognitive load

Subjective measure. A main effect of Condition was revealed (F(2,51) = 5.182, p = 0.009, η^2 = 0.17) (Fig. 5-*left*). The Dancing Condition was perceived as more cognitively demanding ($M_{Dancing}$ = 15.95, SD = 2.50) than the Cycling Condition ($M_{Cycling}$ = 13.11, SD = 3.16; p = 0.049) and the Stepping Condition ($M_{Stepping}$ = 12.50, SD = 4.35; p = 0.009). The main effect of Tolerance Level was none significant (F(1,51) = 0.266, p = 0.608). The interaction Condition*Tolerance Level did not reach significance (F(2,51) = 0.269, p = 0.765).

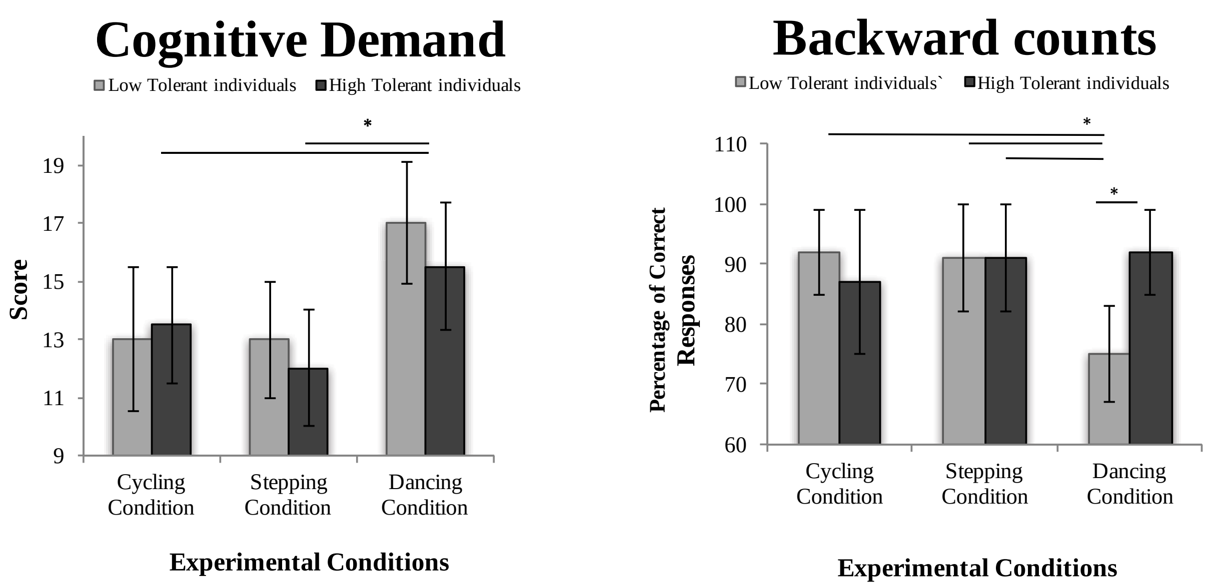


Figure 5: Scores of Cognitive demand (*left*) and Backward counts (*right*) as a function of the condition Cycling, Stepping and Dancing in Low Tolerant individuals (*grey*) and High Tolerant individuals (*black*). Error bars illustrate the confidence intervals 95% around the mean (*p < 0.05).

Objective measure.

Baseline performances. Neither a main effect of the Condition ($F(2,51) = 0.689$, $p = 0.506$) nor a main effect of the Tolerance Level were revealed ($F(1,51) = 1.939$, $p = 0.169$). The interaction Condition*Tolerance Level did not reach significance ($F(2,51) = 0.116$, $p = 0.891$). Thus, before starting the physical activity, the backward counting abilities in Low and High Tolerant individuals were similar across conditions.

Practice measures. Neither a main effect of Condition nor a main effect of the Tolerance Level were observed (Table 3). The interaction Condition*Tolerance Level reached significance ($F(2,50) = 5.499$, $p = 0.007$, $\eta^2 = 0.18$) (Fig. 5-*right*). The Low Tolerant individuals in the Dancing Condition performed less well the backward counting task ($M_{Low} = 75.74$, $SD = 13.68$) than the Low Tolerant individuals in the Cycling ($M_{Low} = 92.23$, $SD = 9.27$) ($p = 0.002$) and in the Stepping Conditions ($M_{Low} = 91.38$, $SD = 9.22$) ($p = 0.009$) and than the High Tolerant individuals in the Dancing ($M_{High} = 92.32$, $SD = 8.84$) ($p = 0.003$) and in the Stepping condition ($M_{High} = 91.35$, $SD = 6.48$) ($p = 0.008$). No main effect of the Assessment Time was revealed. The interactions Assessment Time*Condition and the interaction Assessment Time*Tolerance Level did not reach significance (Table 3).

e) The affective experience during physical exercise

Resting state. A main effect of the Condition was revealed ($F(2,51) = 3.536$, $p = 0.036$, $\eta^2 = 0.12$) with individuals in the Cycling Condition having lower scores in the FS scale ($M_{Cycling} = 2.78$, $SD = 1.81$) than individuals in both the Stepping ($M_{Stepping} = 3.50$, $SD = 1.54$) and the Dancing Conditions ($M_{Dancing} = 2.65$, $SD = 1.76$). No main effects of Tolerance Level was revealed ($F(1,51) = 0.009$, $p = 0.925$). The interaction Conditions*Tolerance Level did not reach significance ($F(2,51) = 2.066$, $p = 0.137$). Thus, before starting the physical activity, individuals in the Cycling Condition presented less positive affective states.

Warm-up measures. Neither a main effect of the Conditions nor a main effect of the Tolerance Level were revealed (Table 3). The interaction Conditions*Tolerance Level did not reach significance ($F(2,50) = 0.673$, $p = 0.515$). Thus, after the warm-up period, the affective states were similar in both Low and High Tolerant individuals across conditions.

Practice measures. No main effect of Condition was revealed ($F(2,50) = 0.066$, $p = 0.937$). A main effect of the Tolerance Level was observed ($F(1,50) = 11.030$, $p = 0.002$, $\eta^2 = 0.19$) with Low Tolerant individuals having lower scores on the Feeling Scale ($M_{Low} = 1.73$, $SD = 1.47$) than the High Tolerant individuals ($M_{High} = 3.10$, $SD = 1.21$). The interaction Condition*Tolerance Level did not reach significance ($F(2,50) = 0.763$, $p = 0.472$). No main effect of the Assessment Time was observed ($F(5,250) = 1.216$, $p = 0.302$). The interaction Assessment Time*Condition did not reach significance ($F(10, 250) = 0.881$, $p = 0.552$). The interaction Assessment Time*Tolerance Level reached significance ($F(5,250) = 4.477$, $p < 0.001$, $\eta^2 = 0.08$). More specifically, a decrease in the affective valence was observed only in the Low Tolerant individuals. The Feeling scale remained constant across time in the High Tolerant groups. Furthermore, differences between Low and High Tolerant individuals were observed throughout (Fig. 6).

Recovery measures. No main effect of Condition was revealed ($F(2,50) = 0.399$, $p = 0.673$). A main effect of the Tolerance Level was observed ($F(1,50) = 4.743$, $p = 0.034$, $\eta^2 = 0.09$) with Low Tolerant individuals having lower scores on the Feeling Scale ($M_{Low} = 2.55$, $SD = 1.30$)

compared to High Tolerant individuals (M_{High} = 3.56, SD = 1.13). The interaction Condition*Tolerance Level was not significant F(2,50) = 0.668, p = 0.517).

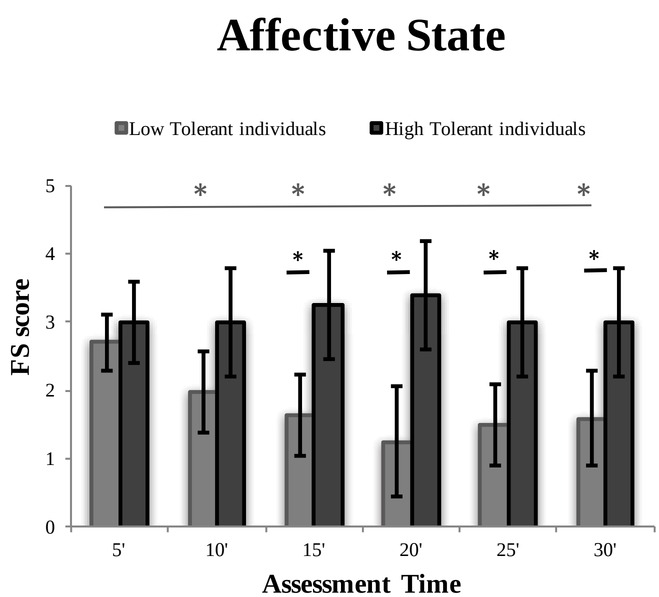


Figure 6: Variations in Feeling Scale as a function of Assessment time for Low Tolerant individuals (*grey*)and High Tolerant individuals (*black*). Error bars illustrate the confidence intervals 95% around the mean.

f) Predicting perception of effort and desire to re-exercise

For demonstrating that the perception of effort is composed of both a physical and a cognitive component, a regression analysis was conducted to assess whether it would be possible to predict the Ratings of Perceived Exertion (using the 6-20 Borg Scale) as a function of the sub-scales of the NASA-tlx questionnaire. Before conducting the regression analysis, we performed a correlational analysis – using Pearson's correlation coefficient - between factors (see Table 4).

The findings argue in favour of a significant role of the perception of both the cognitive ($t = 3.431$, $p = 0.001$, $B = 0.361$) and physical efforts of the motor tasks ($t = 4.771$, $p < 0.001$, $B = 0.502$) (adjusted $r^2 = 0.381$, $F(2,54) = 18.268$, $p < 0.001$).

When participants were instructed to score their desire to re-exercise, there was an absence of Condition main effect ($F(2,50) = 0.937$, $p = 0.398$). A tendency of a Tolerance main effect was revealed ($F(1,50) = 3.805$, $p = 0.056$) with Low Tolerant individuals having lower scores ($M_{Low} = 1.09$, $SD = 1.83$) than that observed in the High Tolerant individuals ($M_{High} = 1.81$, $SD = 1.58$). The interaction Condition*Tolerance did not reach significance ($F(2,50) = 0.074$, $p = 0.929$).

A regression analysis was conducted to reveal a possible prediction of the desire to re-exercise. Before conducting the regression analysis, we performed a correlational analysis were also conducted between factors (see Table 4). The findings argue in favour of a significant role of both the valence component of affective states during practice ($t = 3.292$, $p = 0.002$, $B = 0.405$) and the Heart Rate Frequency during the recovery ($t = 3.885$, $p < 0.001$, $B = 0.494$) (adjusted $r^2 = 0.304$, $F(2,55) = 11.127$, $p < 0.001$). Thus, it seems that the desire to re-exercise is a function of the way one experiences a physical exercise and the way one recovers from it.

	Conditions	**Tolerance Level**	**Total Physical Activity**	**RPE score**	**NASA Cognitive demand**	**NASA Physical demand**	**Desire to re-exercise**	**FS during practice**	**FS during recovery**	**HRF during practice**	**HRF during recovery**
Conditions	--	--	--	--	--	--	--	--	--	--	
Tolerance Level	0.29	--	--	--	--	--	--	--	--	--	
Total Physical Activity	-0.24	0.20	--	--	--	--	--	--	--	--	
RPE	0.07	**-0.38***	0.01	--	--	--	--	--	--	--	
NASA Cognitive demand	0.30	0.05	-0.06	**0.54***	--	--	--	--	--	--	
NASA Physical demand	0.03	**-0.48***	-0.12	**0.54***	0.16	--	--	--	--	--	
Desire to re-exercise	-0.09	0.21	-0.07	-0.17	-0.13	0.17	--	--	--	--	
FS during practice	0.14	**0.73***	0.19	-0.29	0.01	-0.23	**0.40***	--	--	--	
FS during recovery	-0.11	**0.60***	0.20	-0.16	-0.05	-0.17	0.17	**0.68***	--	--	
HRF during practice	**-0.34***	-0.26	-0.04	-0.06	-0.21	0.26	0.29	-0.08	0.20	--	
HRF during recovery	**-0.45***	-0.10	-0.05	-0.22	**-0.47***	0.20	**0.38***	-0.18	0.07	**0.74***	
Counting performances	-0.09	0.15	-0.06	-0.17	**-0.33***	-0.16	0.00	0.18	0.07	-0.11	-0.15

Table 4: Reports the statistical results for the correlation analysis between Conditions, Tolerance Level, Total Physical Activity, RPE score, NASA-tlx sub-scales (Mental demand, Physical demand), Desire to re-exercise, FS during practice, FS during practice, FS during recovery, HRF during practice, HRF during recovery and the Counting performances (*$p < 0.05$).

IV. Discussion

The first essential finding of this original experiment concerns the cognitive definition of physical exercise. More specifically, through the conduction of a self-paced paradigm we revealed that asking individuals to perform a "somewhat difficult" physical exercise means asking them to take into account both the physical and the cognitive load of the task. Furthermore, through the conduction of a dual-task paradigm our results showed that the more physical exercise was challenging during the planning and the execution of the motor behaviour, the more individuals perceived it as cognitively demanding. Hence, our results confirm (1) that the way one perceives the difficulty of a motor task depends on both physical (Eston et al., 2012) and cognitive components (Abbiss et al., 2015) and that physical exercise can be defined from the amount of cognitive resources they require to handle the challenges occurring during their performance (Burzynska et al., 2017; Müller et al., 2017). Finally, the self-paced protocol elaborated through this study leads to confirm that both active and inactive individuals are able to use their affective states to perform a "somewhat difficult" physical exercise for 30 minutes (Eston & Williams, 1988). The results are all the most powerful since (1) the statistical analyses were conducted by statistically controlling for individuals' self-reported weekly physical practice scores and (2) the correlational analyses revealed an absence of correlation between individuals' self-reported weekly physical practice and the depend variables of the study.

The second essential finding of this original experiment concerns the importance of assessing individuals Tolerance level when prescribing physical exercise. More specifically, our results revealed that Low Tolerant individuals perceived physical exercise as more exhausting than did High Tolerant individuals. Furthermore, due to the complexity of the motor tasks, Low Tolerant individuals perceived physical exercise as less pleasant than did High Tolerant individuals. Finally, our results revealed that individuals' affective states experienced during a physical exercise explain, in some part, the individuals' desire to re-exercise; confirming previous studies

(Jekauc, 2015; Wienke & Jekauc, 2016; Zenko et al., 2016). One thing the highlight is that results revealed also that affective states experienced during motor performance was a function of one individual's Tolerance level. Hence, we can suppose that, in daily life, due to the lower affective states that Low Tolerant individuals may experience during the course of a physical exercise they may be more sensitive to drop out a physical exercise program than may do High Tolerant individuals.

a) The specific case of Dancing motor task

Through the conduction of a dual-task paradigm we revealed that performing a counting task while dancing was perceived as more cognitively demanding than performing the same task while stepping or cycling. Dancing was defined as "an equivalent of an enriched environment requiring the ability to learn constantly new choreographies, to integrate multisensory information, to coordinate the whole body and to navigate in space" (Kattenstroth et al., 2013; Müller et al., 2017, p. 2). Thus, in order to handle the challenges occurring during the performance of a Dancing task, individuals require a high amount of cognitive resources. That is may be why, asking individuals to perform also a counting task while dancing leads them to perceive their performance as more cognitively demanding than individuals in Stepping or Cycling condition. Consequently, the results confirmed that physical exercise should be defined and distinguished from the cognitive resources required to perform them (Burzynska et al., 2017; Müller et al., 2017).

b) The possible effect of cognitive demands on the way individuals perceive the physical load of a motor task.

In the Dancing condition, results showed that, contrary to Stepping and Cycling condition, individuals' Heart Rate Frequency (HRF) did not increase throughout the motor performance. However, while the physiological index would not lead to such conclusion, performing a counting task while dancing was perceived (1) as more physically demanding than counting while Stepping and (2) as equally physically demanding than counting while Cycling. Thus, it seems that when individuals have to determine the physical load of a motor task, their judgement is not only based on the physiological or physical changes occurring during the task such as heart rate frequency. In fact, the results echo those revealing that judging the difficulty of a motor task is not based only on individuals' physical abilities but also on their cognitive exhaustion (MacMahon, Schücker, Hagemann, & Strauss, 2014; Pageaux, Lepers, Dietz, & Marcora, 2014; M. R. Smith et al., 2016; M. R. Smith, Marcora, & Coutts, 2015). The Tolerance level and the perception of the difficulty of a motor task

Across conditions (i.e., Cycling, Stepping and Dancing), our results showed that the performance of the dual-task was perceived as more exhausting for Low Tolerant individuals than for High Tolerant individuals. Hence, the results suggest that Low Tolerant individuals do not possess either the physical or the cognitive resources to handle the dual-task paradigm. Furthermore, in the Dancing condition, for a same perception of the cognitive load of the dual-task, Low Tolerant individuals performed less well the counting task than did High Tolerant individuals. The counting task corresponded to an active manipulation of numbers, thus corresponded to an updating task. Hence, the results suggest that, Low Tolerant individuals do not possess as much as updating resources to handle both the counting and the exercising task that possess High Tolerant individuals. The theoretical question now lies in the identification of the nature of the cognitive differences that may exist between Low and High Tolerant individuals. More specifically, updating abilities take part in more general cognitive abilities called executive functions, i.e., a set of processes whose main function is to facilitate the adaptation of the subject to new situations. Hence, we can suppose that in addition to differ in updating efficiency, Low and High Tolerant individuals could also differ in other executive abilities such as inhibiting or shifting ones.

c) Actual results which are not confirming the Reticular-Activating Hypofrontality theory at "somewhat difficult" intensity

The Reticular-Activating Hypofrontality model (RAH) suggests that as long as physique exercise requires large muscle groups, the brain needs to allocate most of the brain metabolic resources to the regions involved in sensory motor processing (Dietrich, & Audiffren, 2011; Audiffren, 2016;). Hence, whereas the posterior cortex and subcortical regions involved in sensory motor processes would benefit from hyper activation, the prefrontal cortex supporting the executive functions should suffer from a deactivation. However, while a decrease of the prefrontal oxygenation is observed during the performance of a near maximal exercise intensity, Rooks and collaborators (2010) reported that activation of the prefrontal cortex during the course of submaximal physical exercise remains stable or even increases. The results of the present study are in line with those of Rooks et al., (2010). Indeed, the results obtained on individuals counting performances revealed no effects of physical exercise or assessment time on the individuals' updating performances. Consequently, results support the idea that performing "somewhat difficult" thus moderate physical exercise does not lead to an impairment of updating abilities.

d) "Somewhat difficult" physical exercise, motor complexity and the theoretical framework of self-control

In active males when running (Feriche et al., 1998) and athletes when cycling (Stojiljković et al., 2004), performing a "somewhat difficult" physical exercise means performing a motor task at an intensity corresponding to the Ventilatory Threshold. Thus, corresponding at an intensity at which the homeostasis starts to be threatened. Hence, in order to be able to continue the physical exercise throughout time, individuals have to really care about the way they are self-regulating their motor behaviour. More specifically, in order to be able to perform the task throughout time, individuals have to efficiently predict the consequences of their motor behaviour without error. If they do not, a possible greater threat of the homeostasis will emerge due to the necessity to allocate cognitive resources to re-adjust the motor output whereas resources are needed to maintain homeostasis and stability within the system. In the framework of the self-control theoretical hypothesis applied to physical exercise (Audiffren & André, 2015) we can hypothesize that self-regulation abilities and thus cognitive functions are all the most required at this intensity to minimize the threaten of the homeostasis. However, since all physical exercise are not equal concerning their motor complexity, the amount of cognitive resources to handle the task may differ; leading to higher perception of effort by individuals when exercising. That is may be the case for Dancing compared to Cycling or Stepping. Furthermore, while some possess enough cognitive resources to handle the demand of the physical exercise others do not. That is may be why Low Tolerant individuals (1) perceived the dual task as more exhausting than High Tolerant individuals and that (2) less well performed the counting task while Dancing. Consequently, the more cognitively “strong” individuals may positively experience the physical exercise while others cannot. That is what we revealed by observing that Low Tolerant individuals perceived physical exercise as less pleasantness that did High Tolerant individuals.

e) Predicting the desire to re-exercise

The results revealed that the desire to re-exercise can be explained at 30% by affective states experienced during practice and heart rate frequency measured during recovery. The results obtained for the predictive powerfulness of affective states echo those revealing that the pleasure experienced during a session is predictive of a future practice (Jekauc, 2015; Zenko et al., 2016). Finally, the results obtained for the predictive role of HRF during recovery lead to suppose that the way one wants to re-exercise can depend on his/her ability to physically and cognitively recover from the physical effort. Hence, the results lead to confirm that the societal question of physical exercise adherence cannot be solved only through the conduction of rational promotional campaigns but also by promoting the essential feature of the way one experiences and recover from a session.

V. Conclusion

This original experimental research allows to consider that physical exercise can be defined from a cognitive standpoint. Through the conduction of a dual-task paradigm we revealed that assessing the cognitive load of physical exercise is possible. Furthermore, such methodology allows to differentiate physical exercise as a function of the cognitive resources required to be performed. Hence, these results suggest a possible redefinition of physical exercise from a cognitive standpoint. We also revealed that the perception of effort is composed by both physical and cognitive components; leading to remember that when asking individuals to select how much they experienced a physical exercise, individuals take into account both the physical and the cognitive loads of the motor task. Finally, we revealed that the Tolerance of exercise intensity may explain why individuals experience positively or negatively a physical exercise; leading to consider this factor in the field of sport psychology.

What's next?

In Study II, we showed that physical exercise requires cognitive resources. Furthermore, we revealed that the way one experiences the difficulty of a motor task is a function of several factors: (1) a physical and a cognitive component, (2) the motor planning complexity of the task and (3) one individual's Tolerance level. Nonetheless, limited factors must to be noted. First, an absence of measure of objective intensity of the physical exercise remains. Second, RPE Borg scale was showed at the start and at the end of the session but not during; suggesting that individuals may not have followed the instruction of practicing at RPE 13 throughout the session. Third, Low and High Tolerant individuals did not have the same degree of self-reported physical practice. Finally, we supposed that Low and High Tolerant individuals may differ from their cognitive processing but we did not measure it.

The objective of Study III was to provide improvements on these different points. We conducted a first experiment with the aim to develop a methodology leading to observe how individuals self-regulate motor task intensity while performing an effortful "somewhat difficult" physical exercise. To better understand the effects of Tolerance level on self-regulation abilities, Low and High Tolerant individuals were compared by experimentally controlling for their self-reported weekly physical practice. Then, we conducted a second experiment with the aim to assess the executive differences between Low and High Tolerant individuals. More specifically, based on the theoretical definition of executive functions (Miyake, 2000) we will show that Low and High Tolerant can be distinguished from their updating, shifting and inhibition abilities, which predicts the use of contrasting self-regulation strategies.

Study III:

A Neuropsychological Approach to the Concept of Tolerance to Effort and its Application to the Self-Regulation model of Physical Exercise

In preparation for submission in Cognitive Psychology

Mauraine CARLIER[1], & Yvonne DELEVOYE-TURRELL[1]*

[1]SCALab, UMR CNRS 9193, Department of psychology, University of Lille, Lille, France

***** Corresponding author
E-mail: yvonne.delevoye@univ-lille3.fr (YD)

These authors contributed equally to this work.

HIGHLIGHTS

1. Tolerance to exercise intensity modulates the self-regulation abilities.
2. Low Tolerant individuals are characterised by less efficient Executive functions and lower Self-efficacy scores than High Tolerant individuals.
3. Tolerance score can be explained up to 36 % by the efficiency of the Executive Functions and the score of Self-Efficacy.

General introduction

Physical exercise is a type of motor activity that requires organisation, planning and sequencing of bodily movements performed in the aim to improve and/or maintain one or more components of physical fitness (American College of Sports Medicine et al., 2010). In the context of identifying the cognitive functions require to implement health behaviours such as physical exercise executive functions were revealed as essential (Buckley, Cohen, Kramer, McAuley, & Mullen, 2014; P. A. Hall & Fong, 2015; Mullen & Hall, 2015). More specifically, since executive system refers to a set of processes whose main function is to facilitate the adaptation of the subject to new situations they are required in the daily life implementation of physical exercise health behaviour (Buckley et al., 2014; Hall & Fong, 2015). In fact, engaging in a regular physical exercise practice requires to adapt ourselves in the self-regulation of everyday costs related to one individual’s desire to engage in physical exercise health behaviour (Mullen, & Hall, 2015). Hence, Daly and collaborators (2014) and Best and collaborators 2014) revealed that individuals which possess the more efficient executive functioning are those who able to engage in long term physical practice. Furthermore, executive functions were also suggested as required to help individuals in the self-regulation of the motor behaviour *during* a physical exercise session (Abbiss et al., 2015; Audiffren & André, 2015). More specifically, the more executive functions would be efficient, the more individuals would be able handle the challenges occurring during the performance of the task (Abbiss et al., 2015; Audiffren & André, 2015). Nonetheless, while some individuals possess such cognitive resources to handle and tolerate the task demands, some others are not able to do so. In such context, the first objective of this original research was to understand how one’ ability to handle a self-paced physical exercise for 30 minutes can be explained through an individual’s tolerance profile. Furthermore, the second objective of this original research was to assess how individuals’ ability to tolerate a physical exercise may be related to an individual’s cognitive executive efficiency.

The way one self-regulates the distribution of energy expenditure throughout an exercise task is extremely important as it predetermines the ability to maintain the intensity of a physical exercise across a given period of time (Abbiss et al., 2015). In cognitive psychology, the term « effortful » conveys the sense that a task actually requires the involvement of executive functions (Gendolla, Tops, & Koole, 2015). More specifically, effort emerges from the match (or the mismatch) between (1) a predicted sensory information sent directly from the motor to the sensory areas of the brain and (2) an actual sensory information received by the sensory areas of the brain directly from the body (Abbiss et al., 2015). If the predicted effort corresponds to the actual one, performing the actual motor behaviour will be interpreted as meaning performing an effort that individuals is able to sustain. However, in the case of a mismatch, the cognitive load caused by the discrepancy between the predicted and the actual effort intensity one will lead individuals to perceive the physical exercise as more effortful than expected. Thus, a self-regulated strategy will lead individuals to adjust their motor output in order to minimize the discrepancy existing between the predicted and the actual effort experienced. In consequence, due to the necessity to constantly determine, compare and re-plan the intensity/speed of movement until a match is attained, cognitive functions are needed.

The executive functions are defined as the most evolutionary elaborated cognitive functions for controlling, regulating and adjusting behaviour (Koziol et al., 2011). The most wide spread model in neuropsychology is the one proposed by Miyake and collaborators (2000) that define executive functions by its elementary components of shifting, updating and inhibiting. The shifting ability refers to individual's ability to shift back and forth between multiple tasks, operations or mental sets (Monsell, 1966 – as cited by Miyake et al., 2000). The updating ability refers to the monitoring and the coding of incoming information for relevance to the task by replacing old, no longer relevant information with newer, more relevant information (Morris & Jones, 1990 – as cited by Miyake et al., 2000). Finally, the inhibiting ability concerns one's capacity to voluntary inhibit dominant, automatic or prepotent responses which are no longer relevant for the on-going motor performance (Miyake et al., 2000). As such, executive functions would play a key role in integrating the information emerging from different cortical or subcortical regions (Cisek, & Kalaska, 2010; Koziol et al., 2011) in order to maintain a goal-oriented behaviour (Blair & Ursache, 2011; Otero & Barker, 2014). Many paper-and-pencil neuropsychological tests were developed in order to assess individuals' executive efficiency. However, due to the higher-order role of these functions and their interrelationships, few of them allow to assess "purely" the elementary components (Miyake et al., 2000). The task used in this experimental research were selected as a function of their purity defined by Miyake et al. (2000).

Numerous studies have confirmed the impact of executive exertion on whole-body endurance performance (MacMahon et al., 2014; Pageaux et al., 2014; Smith et al., 2016, 2015). More specifically, before asking individuals to perform a motor task, authors asked them to do a Stroop task for 30 minutes. The objective of the cognitive task was to exhaust mentally individuals to reveal the impact of weakened cognitive functions during the physical performance. Results revealed that previously exhausting individuals' executive functions impacts the way individuals are able to cognitively handle the difficulty of their motor performance (MacMahon et al., 2014; Pageaux et al., 2014; Smith et al., 2016, 2015). Interestingly, Smith and colleagues demonstrated that fatigue induced by executive exertion impaired both prolonged intermittent (Smith et al., 2015) and graded (Smith et al., 2016) running exercises. The results are all the most powerful that executive exhaustion did not alter individuals' physiological responses to endurance exercise (Marcora, Staiano, & Manning, 2009; Pageaux, Marcora, & Lepers, 2013).

In the present study, the working hypothesis was that for similar self-reported physical intensities, individuals with weaker executive functions will have weaker resistance to sensorial feelings of discomfort than individuals possessing efficient executive control. As a consequence, individuals with poor executive functions should self-pace the physical session at low intensities. Finally, we also hypothesised that efficiency of executive functions would be related to the conception of Tolerance. The more individuals possess efficient executive control, the more they should be able to resist to pain or discomfort while exercising.

Experiment 1: what predicts my self-regulated power output after 30’ of moderate physical exercise?

I. Introduction

Self-regulation abilities are described as playing a central role in the degree of engagement in physical exercise. More specifically, the more one is able to negotiate with physical cost and mental effort, the more one will be physically active (Mullen, & Hall, 2015). In the field of sport psychology, the Tolerance to effort is defined as the ability to continue exercising at levels of intensity associated with discomfort and displeasure (Ekkekakis et al., 2005). For now, Tolerance score has been shown to be predictive of the feelings experienced during physical practice (Ekkekakis et al., 2005), the ability to continue a physical exercise after the VT occurrence (Ekkekakis et al., 2005), the physical effort produced (Hall et al., 2014) and the oxygen consumed (Schneider & Graham, 2009). Although the self-regulation abilities have been revealed as important for long-lasting engagement (Buckley et al., 2014a), no studies have reported their central role *during* a single bout of physical exercise. Hence, the aim of the first experiment was to use a self-paced protocol to reveal that during 30 minutes of a physically and cognitively “somewhat difficult” exercise (RPE 13 on the 6-20 Borg Scale) individuals will self-regulate exercise intensity. Because of differences in pain sensitivity and tolerance (Mogil, 1999) as well as in the predicted levels of acceptable sensory stimulations (Abbiss et al., 2015), we hypothesized that the self-regulation profiles will be different between Low and High Tolerant individuals. More specifically, for a similar level of perceived effort (i.e., “somewhat difficult”), High Tolerant individuals should possess greater self-regulation abilities and be able to produce greater intensity of physical exercise in comparison to Low Tolerant individuals, with similar heart rate frequencies.

II. Method

a) Participants

A total of 42 subjects volunteered to take part in the study, 16 men and 26 women (M_{age}= 22.93 ± 3.89 years, M_{BMI}= 25.13 ± 6.19 kg.m-2). All subjects obtained a medical certificate from their medical physicians. Before the beginning of the study, each volunteer read an information letter and completed a written consent form. The study was approved by the Ethics Committee for behavior human studies of the University of Lille. Participants were asked not to participate in any physical training 48 hours before their inclusion.

b) Materials and Procedure

Assessment of the tolerance of exercise intensity

The PRETIE-Q was used to assess the variables of preference for and tolerance to exercise intensity (Ekkekakis, Hall, Petruzzello, 2005). The eight-item Tolerance scale contained four items that targeted high exercise tolerance (e.g., "I always push through muscle soreness and fatigue when working out") and four items that targeted low exercise tolerance (e.g., "During exercise, if my muscles begin to burn excessively or if I find myself breathing very hard, it is time for me to ease off"). Each item was composed of a 5-point response scale (1 = "I totally disagree"; 2 = "I disagree"; 3 = "Neither agree or disagree"; 4 = "I agree"; 5 = "I strongly agree"). A high score of tolerance of exercise intensity corresponds to a high capacity to pursue the physical activity although it becomes uncomfortable or unpleasant (Ekkekakis, Hall, Petruzzello, 2005). To obtain two contrasting groups, a median tolerance score was calculated across individuals. Participants with scores lower than the median (21) were considered as Low.

Self-reported physical activity assessment

The IPAQ (International Physical Activity Questionnaire – Craig et al., 2003) was used to assess the amount of physical activity practiced by the participants as a function of the reported intensity (expressed in METs - Metabolic Equivalent of Task - for 3 different categories: low vs. moderate vs. vigorous), of duration (time in minutes) and of the number of days declared per week (METs-minute/week). The feature of this questionnaire is to consider the overall self-reported physical activity level (including daily activities) and not only the physical activity practiced during leisure sports time. Four different measures were obtained: (1) the Total Physical Activity score, which contains the total amount of physical activity practiced (e.g., METs-minute/week$_{_Low}$, METs-minute/week$_{_Moderate}$ and METs-minute/week$_{_Vigorous}$), (2) the Total Low Physical Activity score, (3) the Total Moderate Physical Activity score and (4) the Total Vigorous Physical Activity score.

Physical Exercise session

During the Physical Exercise session, the participants performed 40 minutes of physical activity. Three phases were constituted: the warm-up period (5 minutes), the physical activity period (30 minutes), and the recovery period (5 minutes) - following criterion described in ACSM (2010)The participants pedalled on an electronically ergo-cyclometer (EXC NewBike 700SP, Technogym, Italy). A picture of a path through a forest was projected on a screen (195 cm x 280 cm) placed 250 cm in front of the participants. Pleasant light was also proposed to optimize the pleasant experience of the physical activity (Shaulov & Lufi, 2009). During the warm-up period, participants were asked to pedal at a speed that would allow them to warm-up and to become familiar with the ergo-cyclometer. During the physical activity (30 min), participants were required to pedal at a speed that they felt as "somewhat difficult" on the Borg RPE scale (RPE 13 on the 6-20 Borg Scale). The power-output (PO) and the heart rate frequency (HRF) produced during the three periods were also measured every minute. Nevertheless, for the statistical analyses conducted on the physical activity period, PO and HRF were resampled at one sample every 5 minutes. For all participants, debrief was systematically conducted after the experimental session to explain the aims and the construct of the study.

III. Statistical analyses

ANOVAs were conducted to reveal main effects of Tolerance Level (High versus Low Tolerant) on general demographics. Mixed Model ANCOVAs were conducted to determine effects of Tolerance Level {2} and Assessment Time {8} on the Heart Rate Frequency (HRF) and on the Power Output (PO) while controlling for the self-reported physical activity level. For the HRF, the baseline value was included within the statistical model as covariate. Throughout these analyses, partial eta squares (η^2_p) were calculated to report the effect sizes. Bonferroni-adjusted pairwise comparisons were used when required for the post-hoc analyses.

IV. Results

Demographics

No Tolerance Level main effect was revealed on the Participants' Age ($F(1,40) = 1.747$, $p = 0.194$), and on the Participants' Education Level ($F(1,40) = 1.248$, $p = 0.271$). No Tolerance main effect was observed for the IPAQ scores obtained on the dimensions Total Physical Activity ($F(1,39) = 0.313$, $p = 0.579$), Total Low ($F(1,39) = 2.367$, $p = 0.132$), Total Moderate ($F(1,39) = 0.012$, $p = 0.913$) and Total Vigorous Physical Activity ($F(1,39) = 0.015$, $p = 0.903$). Thus, when considering the entire spectrum of physical activity, the amount of self-reported physical activity practiced weekly did not differ between Low and High Tolerant individuals. A Tolerance Level main effect was revealed on the Participants' Body Mass Index ($F(1,40) = 6.816$, $p = 0.012$, $\eta^2 = 0.16$) with the Low Tolerant group having smaller BMI ($M_{Low} = 22.30$, $SD = 5.38$) compared to the High Tolerant group ($M_{High} = 27.05$, $SD = 6.05$).

No Sex main effect was revealed on the Participants' Age ($F(1,40) = 0.824$, $p = 0.369$), Educational Level ($F(1,40) = 2.147$, $p = 0.151$). A Sex main effect was revealed on the Participants' Body Mass Index ($F(1,40) = 11.329$, $p = 0.002$, $\eta^2 = 0.22$) with the women having smaller BMI ($M_{Women} = 22.87$, $SD = 5.59$) compared to the men ($M_{Men} = 28.79$, $SD = 5.43$). A

Sex main effect was also revealed on the Participants' Tolerance score (F(1,40) = 4.716, p = 0.036, η^2 = 0.11) with the women having smaller Tolerance score (M_{Women} = 20.19 , SD = 2.68) compared to the men (M_{Men} = 22.13, SD = 2.99).

Self-regulation of the Power Output

Warm-up measures. No Assessment Time main effect was revealed on the Power Output (PO) (F(4,160) = 0.431, p = 0.786). No main effect of the Tolerance Level was revealed (F(1,40) = 0.321, p = 0.573). The interaction Assessment Time*Tolerance Level on PO did not reached significance (F(4,160) = 1.669, p = 0.160). Thus, Low and High Tolerant individuals produced similar levels of PO throughout the warm-up period.

Practice measures. Participants were required to cycle at moderate level (RPE 13) for a total period of 30 minutes. Neither a main effect of Assessment Time (F(5,200) = 0.644, p = 0.666) nor a main effect of Tolerance Level were revealed (F(1,40) = 0.603, p = 0.332). The interaction effect between Assessment Time and Tolerance Level reached significance (F(5,200) = 2.683, p = 0.023, η^2 = 0.06) (Fig.1-*left*). Pairwise comparisons confirmed significant differences in the High Tolerance group between PO at 30' and at 5' of practice (Deltameans = 11.00, SE = 24.23, p < 0.001) and between PO at 30' and at 10' of practice (Deltameans = 6.62, SE = 15.29, p = 0.012) with always more physical output produced at 30’. No differences in PO within the session were observed for the Low Tolerant individuals, indicating that they produced the same Power Output at the beginning and end of the session. Finally, the Power Output in High Tolerant individuals at 30’ differed from the Power Output in Low Tolerant individuals at 5’ (Deltameans = 32.38, SE = 16.19, p = 0.023) and at 30’ (Deltameans = 33.85, SE = 16.93, p = 0.013) (Fig. 1-*left*).

Recovery measures. Results revealed an absence of main effect of Assessment Time (F(4,160) = 0.058, p = 0.994). No main effects of the Tolerance Level were revealed (F(1,40) = 0.186, p = 0.669). The interaction Assessment Time*Tolerance Level did not reach significance (F(4,160) =

0.166, p = 0.955). Thus, Low and High Tolerant individuals self-regulated their Power Output in the same way during the Recovery period.

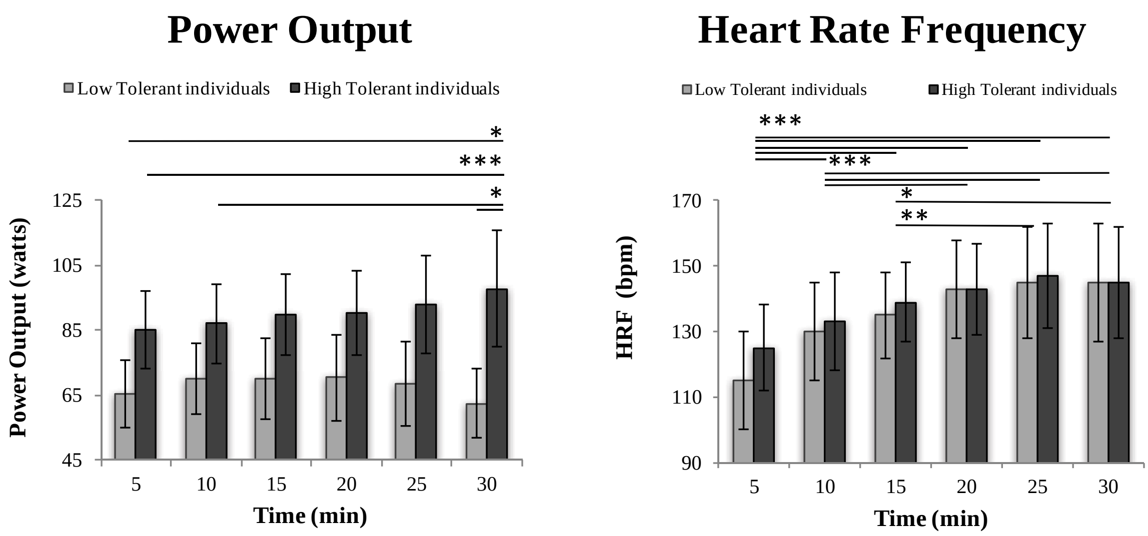


Figure 1: Variations in Power Output (*left*) and Heart Rate Frequency (*right*) as a function of Assessment Time in the Low Tolerant individuals (*grey*) and in the High Tolerant individuals (*black*). Error bars illustrate the confidence intervals 95% around the mean (*p < 0.05, **p < 0.01, ***p < 0.001).

Cardiac Frequency

Resting state Cardiac Frequency. No main effects of the Tolerance Level were revealed (F(1,28) = 0.116, p = 0.737). Thus, Low and High Tolerant individuals had the same Heart Rate Frequency before starting the physical exercise.

Warm-up measures. An Assessment Time main effect was revealed (F(4,112) = 6.809, p < 0.001, η^2 = 0.20). The Heart Rate Frequency was lower at the beginning of the Warm-up period compared to that measured at 3'(Deltameans = 5.20, SE = 2.60, p = 0.007), at 4' (Deltameans = 6.37, SE = 3.19, p < 0.001) and at 5' (Deltameans = 7.64, SE = 3.82, p < 0.001). No main effects of the Tolerance Level were revealed (F(1,28) = 0.149, p = 0.702). The interaction Assessment

Time*Tolerance Level did not reach significance (F(4,112) = 0.742, p = 0.565). Thus, the Cardiac Frequency increased through the Warm-up Period for both Low and High Tolerant individuals in a similar way.

Practice measures. An Assessment Time main effect was revealed (F(5, 140) = 37.585, $p < 0.001$, $\eta^2 = 0.57$) (Fig. 1-*right*). More specifically, the HRF at 5' differed from HRF at 10' (Deltameans = 12.17, SE = 9.49, $p < 0.001$), from HRF at 15' (Deltameans = 17.49, SE = 11.89, $p < 0.001$), from HRF at 20' (Deltameans = 21.56, SE = 13.71, $p < 0.001$), from HRF at 25' (Deltameans = 25.75, SE = 14.19, $p < 0.001$) and from HRF at 30' (Deltameans = 24.14, SE = 16.7, $p < 0.001$). Moreover, HRF at 10' differed from HRF at 20' (Deltameans = 9.39, SE = 7.29, $p < 0.001$), from HRF at 25' (Deltameans = 13.58, SE = 8.91, $p < 0.001$) and from HRF at 30' (Deltameans = 11.96, SE = 12.03, $p < 0.001$). Finally, HRF at 15' differed from HRF at 25' (Deltameans = 8.27, SE = 6.55, p = 0.008) and from HRF at 30' (Deltameans = 6.65, SE = 9.49, p = 0.041). No main effects of the Tolerance Level were observed (F(1,28) = 0.091, p = 0.765). The interaction Assessment Time*Tolerance Level did not reach significance (F(5,140) = 1.005, p = 0.417). Thus, the Cardiac Frequency increased in the same way through the RPE 13 Period for both Low and High Tolerant individuals.

Recovery measures. An Assessment Time main effect was revealed (F(4,112) = 8.169, $p < 0.001$, $\eta^2 = 0.23$). The Heart Rate Frequency was higher at the beginning of the Recovery period compared to 38'(Deltameans = 8.33, SE = 4.17, p = 0.001), 39' (Deltameans = 9.76, SE = 4.88, $p < 0.001$) and 40' (Deltameans = 10.11, SE = 5.05, $p < 0.001$). No main effects of the Tolerance Level were revealed (F(1,25) = 0.003, p = 0.958). The interaction Assessment Time*Tolerance Level did not reach significance (F(4,112) = 1.238, p = 0.299). Thus, the Cardiac Frequency decreased during the Recovery Period in both Low and High Tolerant individuals in a similar way.

V. Discussion

The results revealed that for a same perception of physical and cognitive effort ("somewhat difficult"; RPE 13 on the 6-20 Borg Scale) the Heart Rate Frequency did not differ between Low and High Tolerant groups. However, even if the perception of exertion and the Heart Rate Frequency were similar, High Tolerant individuals were characterized by greater intensities of physical exercise. During the course of the motor performance, High Tolerant individuals increased the Power Output produced while the Power Output of the Low Tolerant individuals remained constant. Hence, when reaching the last 5 minutes of the session, distinct profiles characterized our groups of participants as a function of their Tolerance score. Indeed, High and Low Tolerant individuals distinguished themselves progressively during the session by revealing contrasting ways of self-regulating power output and different intensity of physical exercise at the end of the session. To further understand these differences in self-regulation strategies, a second study was conducted focusing on the efficiency of executive functions in Low and High Tolerant individuals.

Experiment 2: What is Tolerance of exercise intensity?

I. Introduction

Executive functions are defined as the most elaborated cognitive processes for adjusting, regulating and adapting human behaviour (Koziol, Budding, and Chidekel, 2011). They are required for "modulat[ing] the operation of various cognitive subprocesses and thereby the dynamics of human cognition" (Miyake, 2000). On the other hand, the self-efficacy is defined as “beliefs in one’s capabilities to organize and execute the course of action required for producing given attainments” (Bandura, 1997). In the context of physical exercise, both executive functions and self-efficacy would hence play an antecedent role in effective self-regulation of physical activity (Mullen et Hall, 2015). As a consequence, the more individuals possess efficient executive functions, the more they may engage in regular physical activities thanks to their confidence in their abilities to handle their engagement in weekly physical activity (McAuley). Hence, the aim of this second experiment was to assess a possible correlation between individuals’ Executive Functions, Self-Efficacy and Tolerance of exercise intensity. We hypothesized that Low and High Tolerant individuals will be characterized by different levels of efficiency in their Executive Functioning and by different Self-Efficacy scores. We also hypothesized that the individuals’ variability in Tolerance scores can be predicted up to some extent by scores in Executive Functions and Self-Efficacy.

II. Method

a) Participants

A total of 39 subjects, of which 20 participants who did not engage in study 1, volunteered to take part in experiment 1, 14 men and 25 women (M_{age} = 23.38 ± 5.58 years, M_{BMI} = 24.74 ± 5.83 kg.m-2). All participants were right-handed. Before the beginning of the study, each volunteer read an information letter and completed a written consent form. The study was approved by the Ethics Committee for behaviour human studies of the University of Lille.

b) Materials and Procedure

The same material than in study 1 was used here to assess the Self-Reported Physical Activity and the Tolerance of exercise intensity.

Assessment of the Self-efficacy

The SCI Exercise Self-Efficacy Scale (ESES – Kroll, Khen, Ho, & Groah, 2007) was used to assess the Self-Efficacy of participants. The scale instructs respondents to indicate on the 4-point rating scale (1 = not at all true, 2 = rarely true, 3 = moderately true, 4 = always true) how confident they are with regard to carrying out regular physical activities and exercise.

Assessment of the Executive Functions

The three tasks assessing the executive functioning of participants are the same than those used by Miyake et al. (2000) and a brief description is presented in the following section.

Assessment of the shifting ability

The computerized task used was the **number-letter task**, adapted from Rogers and Monsell (1995). A number-letter pair (e.g., 7G) was presented in one of four quadrants on the computer screen. The participants were instructed to indicate whether the number was odd or even (2, 4, 6, and 8 for even; 3, 5, 7, and 9 for odd) when the number-letter pair was presented in either of the top two quadrants. Participants were required to indicate whether the letter was a consonant or a vowel (G, K, M, and R for consonant; A, E, I, and U for vowel) when the number-letter pair was presented in either of the bottom two quadrants (Fig. 2-*Bottom-right*). The number-letter pair was presented only in the top two quadrants for the first block of 32 target trials (Number Condition), only in the bottom two quadrants for the second block of 32 target trials (Letter Condition), and in a clockwise rotation around all four quadrants for the third block of 128 target trials (Shifting

Condition). Thus, the trials within the first two blocks required no task shifting, whereas half of the trials in the third block required participants to shift between the two types of categorization operations. In all trials, the participants responded by a button press, and the next stimulus was presented 150 ms after the response was given. The reaction times (RT), the percentage of correct responses and the shift cost were the dependent variables. The shift cost for this task was the difference between the mean RTs of the shifting condition (third block) and of the reference condition (first and second blocks).

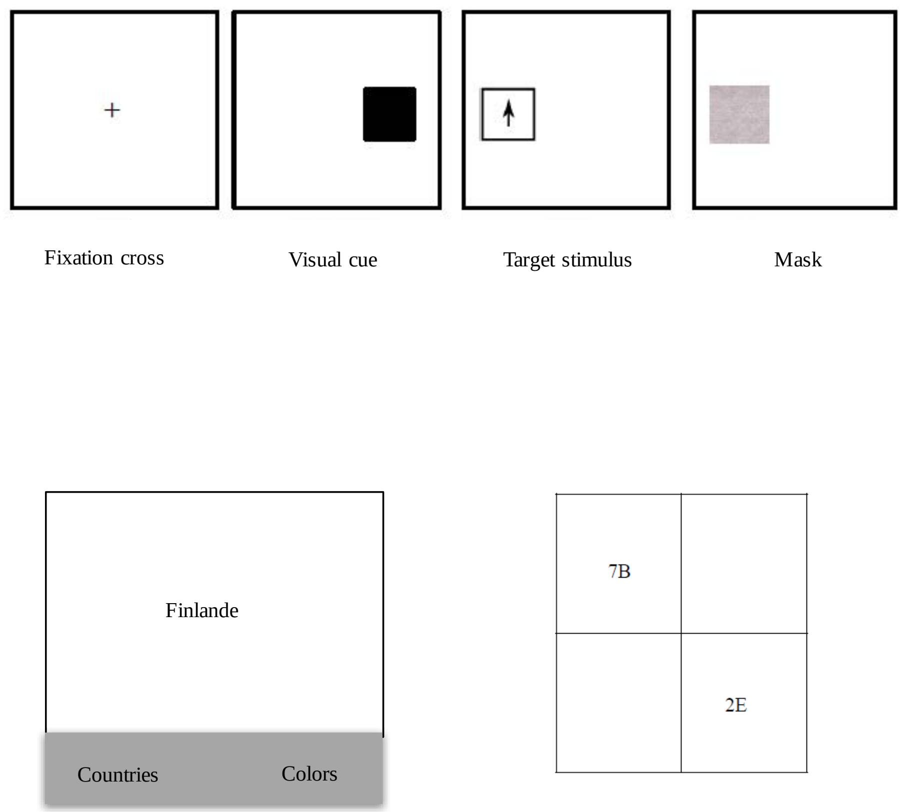


Figure 1: Representation of the Antisaccade task (*Top*), the Keep-track task (*Bottom left*) and Number-Letter task (*Bottom right*).

Assessment of the updating ability

The computerized task used was the ***keep-track task*** (adapted from Yntema, 1963). In each trial of the keep track task, participants were first shown several target categories, which appeared at the bottom of the computer screen. Fifteen words, including 2 or 3 exemplars from each of six possible categories (animals, colours, countries, family, clothing and metals), were then presented serially and in random order for 1500 ms, with the target categories remaining at the bottom of the screen (Fig. 2-*Bottom-left*). The task was to remember the last word presented in each of the target categories and then, to recall orally these words to the experimenter at the end of the trial. Three types of conditions were possible. In Condition 1, participants were instructed to recall 2 words. In Condition 2, participants were required to recall 3 words. In Condition 3, participants were instructed to recall 4 words. For example, if the target categories were metals, animals, and countries. Then, at the end of the trial, participants recalled the last metal, the last animal, and the last country presented within the list. Thus, to perform correctly the task, participants had to closely monitor the words presented and update their working memory representations for the appropriate categories when the presented word was a member of one of the target categories. Before this task began, participants saw all six categories and the exemplars in each to ensure that they knew to which category each word belonged. Participants were also given the possibility to practice for three trials corresponding to the three conditions. Then, they performed four trials with two target categories, four with three target categories and four trials with four target categories, recalling a total of 36 words. The number of words recalled correctly in each condition was taken as the dependent measures.

Assessment of the inhibiting ability

The computerized task used was the ***antisaccade task*** (adapted from Roberts, Hager, & Heron, 1994). During each trial, a fixation point was first presented in the middle of the computer screen for a variable amount of time (one of nine times between 1500 and 3500 ms in 250-ms intervals).

A visual cue (0.4 °) was then presented on one side of the screen (e.g., left) for 225 ms, followed by the presentation of a target stimulus (2.0 °) on the opposite side (e.g., right) for 150 ms before being masked by a gray cross-hatching. The visual cue was a black square, and the target stimulus consisted of an arrow inside an open square. The participants' task was to indicate the direction of the arrow (left, up, or right) with a button press response. Given that the arrow appeared for only 150 ms before being masked, participants were required to inhibit the reflexive response of looking at the initial cue (a small black square) because doing so would make it difficult to correctly identify the direction of the arrow (Fig. 2-*Top*). Three types of trials were possible. For the Congruent trials, the direction of the arrow matched with the side of the screen (e.g., the direction of the arrow is left and the arrow appeared on the left side of the screen). For the Incongruent trials, the direction of the arrow was opposite to the side at which appeared the arrow (e.g., the direction of the arrow is left and the arrow flashes on the right side of the screen). For the Neutral trials, the arrow pointed up. The cues and targets were both presented 3.4 cm away from the fixation point (on opposite sides) and the participants were seated 70 cm from the computer monitor. Thus, the total subtended visual angle from cue to target was approximately 21.4°. The participants practiced on 22 trials and then, received 90 target trials. The proportion of correct responses and the mean reaction times for each type of trial served as the dependent measures. We also measured the error cost by calculating the mean reaction times of those trials following an error.

III. Statistical analysis

ANOVAs were conducted to reveal main effects of Tolerance Level (High versus Low Tolerant) on general demographics. ANCOVAs were conducted to determine effects of Tolerance Level {2} while controlling for the self-reported physical activity level. Throughout these analyses, partial eta squares (η^2_p) were calculated to report the effect sizes. Bonferroni-adjusted pairwise comparisons were used when required for the post-hoc analyses.

A regression analysis was conducted to explain the Tolerance of exercise intensity. Before conducting the analysis of the regression, we conducted correlational analysis – using Pearson's correlation coefficient - between factors. The objective was to examine the relationship between the Tolerance of exercise intensity scores, the Total Physical Activity of the IPAQ, the performances in the Executive Functions tasks and the Self-Efficacy scores. Conducting an analysis of the correlations allowed us to choose the regression factors by decreasing a more as possible the overlap between factors. The regression analysis was then conducted to highlight potential neuropsychological predictors of the Tolerance of exercise intensity. The regression analysis was conducted from a descendant perspective by considering the different factors and taking out those which did not play a significant role in the regression analysis.

IV. Results

a) Demographics

No Tolerance Level main effect were revealed on the Participants' Age ($F(1,37) = 0.916$, $p = 0.345$), on the Participants' Body Mass Index ($F(1,37) = 2.087$, $p = 0.157$) and on the Participants' Educational Level ($F(1,37) = 1.082$, $p = 0.305$). No Tolerance main effects were observed for the IPAQ scores obtained on the dimensions Total Physical Activity ($F(1,36) = 2.177$, $p = 0.149$), Total Low ($F(1,36) = 0.454$, $p = 0.505$), Total Moderate ($F(1,36) = 1.407$, $p = 0.243$) and Total Vigorous Physical Activity ($F(1,36) = 2.578$, $p = 0.117$). Thus, when considering the entire spectrum of physical activity, the amount of self-reported physical activity practiced weekly did not differ between Low and High Tolerant individuals. A Tolerance Level main effect was revealed on the Participants' Self-Efficacy score ($F(1,37) = 6.804$, $p = 0.013$, $\eta^2 = 0.16$) with the Low Tolerant individuals considering themselves as less efficient ($M_{Low}= 25.15$, $SD = 5.51$) compared to the High Tolerant individuals ($M_{High} = 29.20$, $SD = 4.10$). Thus, even if Low and High Tolerant individuals practiced the same amount of physical activity, the High

Tolerant individuals felt themselves as more confident in the context of exercising compared to the Low Tolerant individuals.

No Sex main effects were revealed on the Participants' Age ($F(1,37) = 0.397$, $p = 0.532$), on the Participants Educational Level ($F(1,37) = 3.877$, $p = 0.056$), on the Participants' Self-Efficacy score ($F(1,37) = 1.821$, $p = 0.185$) as well as on the Participants' Tolerance score ($F(1,37) = 0.611$, $p = 0.439$). A Sex main effect was revealed on the Participants' Body Mass Index ($F(1,37) = 24.776$, $p < 0.001$, $\eta^2 = 0.40$) with the women having smaller BMI ($M_{Women} = 22.01$, $SD = 4.75$) compared to the men ($M_{Men} = 29.61$, $SD = 4.23$).

b) Executive functions

Shifting

Correct Answers

No Condition main effect was revealed on the participants' percentages of Correct Response ($F(2,109) = 1.082$, $p = 0.335$). Individuals had the same ability to decide whether the letter was a vowel or consonant ($M_{Letter\_Condition} = 100.00$, $SD = 0.00$), whether the number was even or odd ($M_{Number\_Condition} = 100.00$, $SD = 0.00$) or when they had to switch between rules ($M_{Shifting\_Conditon} = 99.64$, $SD = 2.11$). No Tolerance Level main effect was revealed on the participants' percentages of Correct Response ($F(1,109) = 0.528$, $p = 0.469$). Thus, the Low Tolerant individuals had the same ability to correctly perform the task ($M_{Low} = 100.00$, $SD = 0.00$) than the High Tolerant individuals ($M_{High} = 99.77$, $SD = 1.70$). The interaction Condition*Tolerance Level did not reach significance ($F(2,109) = 1.087$, $p = 0.341$), suggesting that Low Tolerant individuals had the same ability to correctly perform the task than the High Tolerant individuals whatever the complexity of the task.

Reaction times analyses

Statistical analyses were conducted only on Correct Response. An effect of Condition was revealed on the participants' reaction times ($F(2,106) = 267.043$, $p < 0.001$, $\eta^2 = 0.34$). When individuals had to switch between rules (Shifting Condition), they needed more time to respond ($M_{Shifting} = 1316.51$ ms, SD = 371.92) compared to when they had only to decide whether the letter was a vowel or a consonant ($M_{Letter} = 926.11$ ms, SD = 228.99) ($p < 0.001$) or if the number was even or odd ($M_{Number} = 902.12$ ms, SD = 226.81) ($p < 0.001$) (Fig. 5-*right*). An effect of the Tolerance Level was revealed on the participants' reaction times ($F(1,106) = 6.128$, $p = 0.014$, $\eta^2 = 0.06$). The Low Tolerant individuals responded slower ($M_{Low} = 1107.52$ ms, SD = 319.20) compared to the High Tolerant individuals ($M_{High} = 991.94$ ms, SD = 352.45). The interaction Condition*Tolerance Level did not reach significance ($F(2, 106) = 0.039$, $p = 0.962$), suggesting that both High and Low tolerant individuals needed more time when they had to switch between rules.

Shift cost

These findings were confirmed when calculating the shifting cost (Miyake, 2000). No Tolerance main effects reached significance both (1) when subtracting the average reaction times obtained in the Number Condition from the average reaction times obtained in the Shifting Condition ($F(1,34) = 0.012$, $p = 0.912$) and (2) when subtracting the average reaction time obtained in the Letter Condition to the average reaction times obtained in the Shifting Condition ($F(1,34) = 0.002$, $p = 0.971$).

Updating

A main effect of Condition was revealed on the number of correct words recalled by the participants ($F(2,106) = 4.093$, $p = 0.019$, $\eta^2 = 0.07$). The number of correct words recalled was higher when individuals had to recall 3 words ($M_{3words} = 1.84$, SD = 0.25) compared to when they had to recall 4 words (M_{4words} = 2.06, SD = 0.54). An effect of the Tolerance Level was revealed on the number of correct words recalled ($F(1,106) = 16.827$, $p < 0.001$, $\eta^2 = 0.13$). Results are presented in Figure 5-*left*. Low Tolerant individuals recalled fewer words (M_{Low} = 1.74, SD = 0.47) than High Tolerant individuals (M_{High} = 2.04, SD = 0.46). The interaction Condition*Tolerance Level did not reach significance ($F(2, 106) = 1.515$, $p = 0.225$), suggesting that Low Tolerant individuals were characterized overall by less efficient updating abilities than High Tolerant individuals, whatever the complexity level of the updating task.

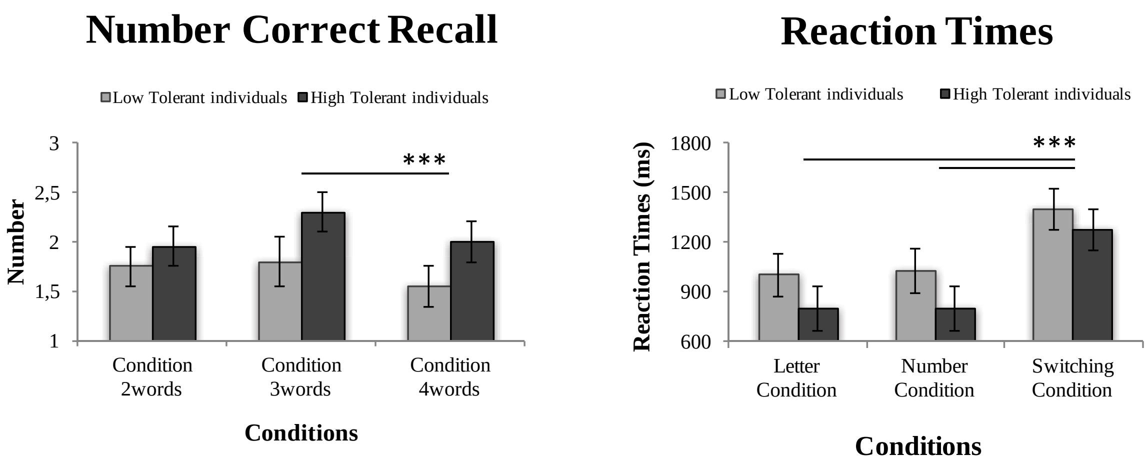


Figure 2: Updating performances. Number of Correct Recall *(left)* and Reaction Times (*right*) as a function of conditions: 2 words, 3 words, 4 words in the Low Tolerant individuals (*grey*) and in the High Tolerant individuals (*black*). Error bars illustrate the confidence intervals 95% around the mean (*** p<0.001).

Inhibition

Correct Answers

An effect of the Condition was revealed on the participants' mean percentages of Correct Responses ($F(2,109) = 7.829$, $p < 0.001$, $\eta^2 = 0.13$). Condition means in Correct Responses were higher in the Neutral Condition ($M_{Neutral}$ = 98.60, SD = 2.45) than in the Incongruent Condition ($M_{Incongruent}$ = 88.21, SD = 16.99) ($p < 0.001$) and the Congruent Condition ($M_{Congruent}$ = 92.00, SD

= 11.77) (p = 0.044) (Fig. 3-*Top left*). No Tolerance Level main effect was revealed on the means Correct Responses (F(1,109) = 0.012, p = 0.914). Thus, both High and Low Tolerant individuals performed equally well the task. The interaction Conditions*Tolerance Level did not reached significance (F(2,109) = 1.572, p = 0.212), indicating that both High and Low Tolerant individuals performed less well in the Incongruent and Congruent Conditions than in the Neutral one.

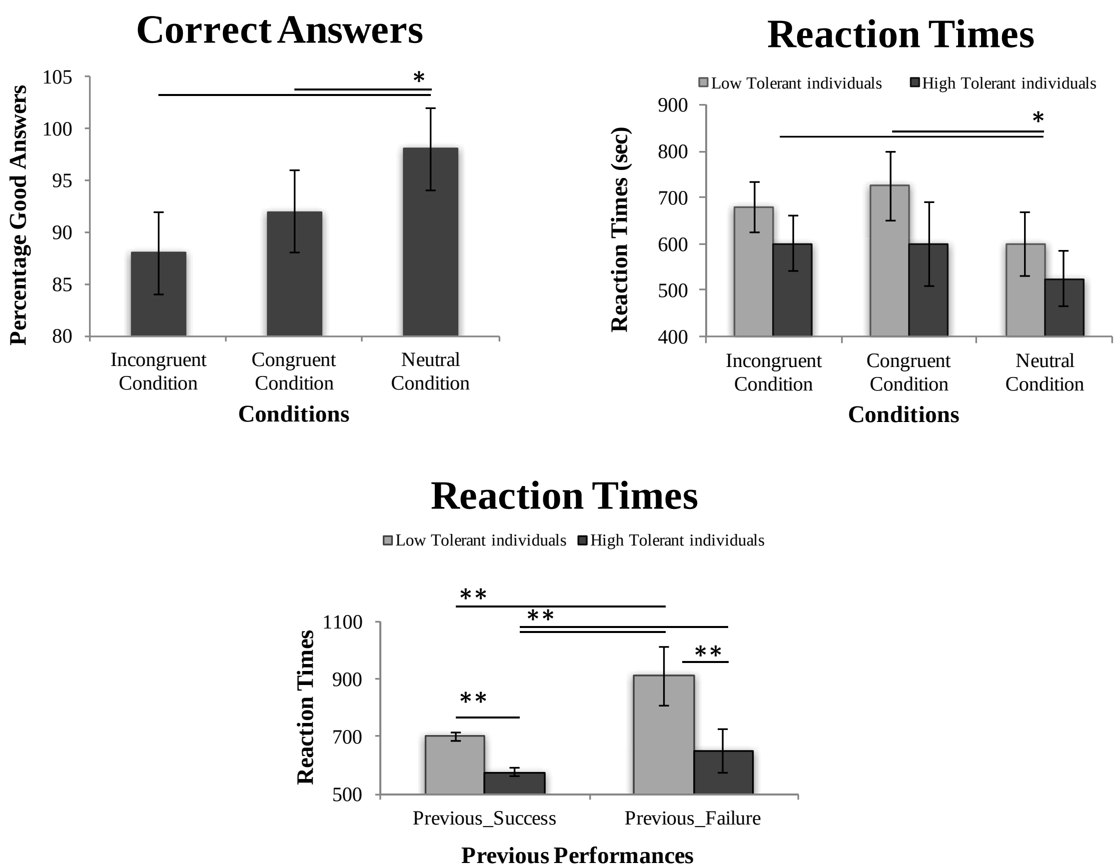


Figure 3: Inhibition performances. Correct Answers (*Top left*) and Reaction Times (*Top right*) as a function of conditions: Incongruent, Congruent and Neutral in the Low Tolerant individuals (*grey*) and in the High Tolerant individuals (*black*). Reactions Times are also represented as a function of previous performance (*Bottom*): previous success and previous failure, in the Low Tolerant individuals (*grey*) and in the High Tolerant individuals (*black*). Error bars illustrate the confidence intervals 95% around the mean (*p<0.05, **p<0.01).

Reaction time analyses

Statistical analyses were conducted only on Correct Responses. An effect of Condition was revealed on the participants' reaction times ($F(2,109) = 3.763$, $p = 0.026$, $\eta^2 = 0.06$). Mean reaction times were slower in the Congruent Condition ($M_{Congruent} = 665.92$ ms, SD = 207.30) than in the Neutral Condition ($M_{Neutral} = 562.66$ ms, SD = 145.28) ($p = 0.025$) (Fig. 3-*Top right*). An effect of the Tolerance Level was revealed ($F(1,109) = 8.168$, $p = 0.005$, $\eta^2 = 0.07$) (Fig. 3-*Top right*). The Low Tolerant individuals revealed slower reaction times ($M_{Low} = 667.64$ ms, SD = 202.02) than High Tolerant individuals ($M_{High} = 574.76$ ms, SD = 136.82). The interaction Condition*Tolerance Level did not reach significance ($F(2, 109) = 0.0617$, $p = 0.940$).

Cognitive control

All of the participants' responses were taken into account (both correct and incorrect responses). In this section, we assessed whether the Reaction Time during one trial could depend on (1) the Previous Performance of individuals (success vs. failure) and (2) on the Tolerance Level of the participants.

An effect of the Previous Performance was revealed on the participants' mean reaction times ($F(1,3481) = 34.847$, $p < 0.001$, $\eta^2 = 0.01$). Mean reaction times were longer when participants previously failed ($M_{Previous\_Failure}= 780.58$ ms, SD = 361.27) compared to when they previously successed ($M_{Previous\_Success}= 627.29$ ms, SD = 255.98). No Condition main effects were revealed on mean reaction times ($F(2,3481) = 0.264$, $p = 0.768$). Thus, when considering both correct and incorrect responses, the participants' reaction times during a trial were not depending on the previous condition (Congruent vs. Incongruent vs. Neutral). A Tolerance Level effect was confirmed ($F(1,3481) = 44.587$, $p < 0.001$, $\eta^2 = 0.01$). The Low tolerant individuals responded slower ($M_{Low} = 704.15$ ms, SD = 317.97) than the High Tolerant individuals ($M_{High} = 583.43$ ms, SD = 201.91). More importantly, the interaction Previous Performance*Tolerance Level reached significance ($F(2, 3481) = 5.790$, $p = 0.0162$, $\eta^2 = 0.001$). Thus, the error cost ($RT_{Previous\_Failure} - RT_{Previous\_Success}$) was greater in Low Tolerant individuals ($Delta_{Low} = 251$ ms) than in High Tolerant individuals ($Delta_{High} = 77$ ms) (Fig. 3-*Bottom*). The interaction Condition*Tolerance Level reached significance ($F(2, 3483) = 9.613$, $p < 0.001$, $\eta^2 = 0.005$). The Low Tolerant individuals responded always slower than the High Tolerant individuals. However, the Reaction times difference between High and Low Tolerant individuals was higher when the Previous trial was an Incongruent Condition ($M_{High} = 574$ ms, SD = 184; $M_{Low} = 850$ ms, SD = 312) than a Congruent Condition ($M_{High} = 648$ ms, SD = 207; $M_{Low} = 765$ ms, SD = 328) and a Neutral Condition ($M_{High} = 650$ ms, SD = 200; $M_{Low} = 800$ ms, SD = 297). The interaction Conditions*Previous Performances did not reach significance ($F(2, 3483) = 1.338$, $p = 0.262$). Thus, the error cost ($RT_{Previous\_Failure} - RT_{Previous\_Success}$) was the same in the three Conditions (Congruent vs. Incongruent vs. Neutral). The triple interaction Conditions*Previous Performances*Tolerance Level reached significance ($F(2, 3483) = 13.211$, $p < 0.001$, $\eta^2 = 0.007$).

Explaining Tolerance variability through Executive Functions efficiency and Self Efficacy score

Correlational analyses – using Pearson’s correlation coefficient – were conducted between factors. Due to the main effect of Tolerance Level observed on these variables, the performances in the Executive Functions tasks corresponded to (1) the average number of correct words recalled in the Updating task, (2) the Error cost in the Inhibition task, and (3) the average Reaction Times in the Shifting condition. The results are presented in Table 1. The model considering the Updating performances and the Self-Efficacy score (observed as correlated to the Tolerance) explained 36 % of the variance of the Tolerance scores (adjusted $r^2 = 0.366$, $F(2,36) = 111.945$, $p < 0.001$). When adding the Inhibition Error cost, an executive functions performance for which an main effect of the Tolerance Level was observed, the model explained 44 % of the variance of the Tolerance score (adjusted $r^2 = 0.442$, $F(3,28) = 9.198$, $p < 0.001$ – Table 2).

	Tolerance	Updating	Inhibition (Error cost)	Switching	Self-Efficacy score
Tolerance	--	--	--		--
Updating	**0.45***	--	--		--
Inhibition (Error cost)	-0.28	0.00	--		--
Switching	0.04	-0.37	0.05	--	--
Self-Efficacy score	**0.47***	-0.01	-0.05	0.15	--
IPAQ	0.20	0.19	-0.13	-0.30	**0.52***

Table 1: Reports the statistical results for the correlation analysis between Tolerance of exercise intensity scores, Total Physical Activity of the IPAQ, Executive Functions performances and Self-Efficacy scores (* : p < 0.05).

	t	*p*	β
Model 1			
Updating	3.354	= 0.002	0.434
Self-Efficacy score	3.307	< 0.001	0.480
F (df), *p*	11.945 (2,36)	$r^2 = 0.399$	r^2 adjusted = 0.366
Model 2			
Updating	3.283	= 0.003	0.461
Self-Efficacy score	3.378	= 0.002	0.461
Inhibition	-1.928	= 0.064	-0.259
F (df), *p*	10.915 (2,29)	$r^2 = 0.429$	r^2 adjusted = 0.390

Table 2: Multiple linear regression analyses for predicting the Tolerance of exercise intensity score as a function of the the performances in the Executive Functions tasks and the Self-Efficacy scores.

V. Discussion

We revealed that even if Low and High Tolerant individuals practice the same amount of physical activity, the High Tolerant individuals considered themselves as more efficient in the context of exercising compared to the Low Tolerant individuals. Moreover, compared to the High Tolerant individuals, the Low Tolerant individuals were characterized by weaker executive functions. Low Tolerance profile included more difficulties in updating information (less number of correct words recalled whatever the difficulty of the task) and more difficulties in inhibiting on-going motor behaviours especially when following a self-initiated error. The results obtained for the updating tasks echo those obtained in Study II. More specifically, Low Tolerant individuals were characterised by less efficient updating abilities than High Tolerant individuals. An effect of the Tolerance Level was also observed on the reaction times in the shifting task. However, these results seem to reveal more a general tendency to respond slower than a specific less efficient shifting ability. Finally, the results obtained during the regression analysis, revealed that the Tolerance of exercise intensity could be explained at 36% by Updating abilities and Self-Efficacy scores. Furthermore, the Tolerance of exercise intensity could be predicted 39 % when including the Updating and the Inhibiting abilities as well as the Self-Efficacy scores. Hence, through the conduction of this second experiment we argued in favour of a neuropsychological approach of the Tolerance of effort.

VI. General discussion

Executive functions are defined as the most evolutionary elaborated cognitive functions for controlling, regulating and adjusting behaviour (Koziol et al., 2011). In such context, the self-control theoretical hypothesis supposes that during the course of a physical activity executive functions may be required to help individuals in the self-regulation and self-control of their effort (Audiffren & André, 2015). In active males when running (Feriche et al., 1998) and athletes when cycling (Stojiljković et al., 2004), performing a “somewhat difficult” physical exercise means performing a motor task at an intensity corresponding to the Ventilatory Threshold. Thus, corresponding at an intensity at which the homeostasis starts to be threatened. In such a context, due to the necessity to constantly self-regulating the motor behaviour in order to not increase the threaten of the homeostasis, executive functions are all the most required.

a) Self-regulation abilities and Tolerance of effort

During the experiment 1, we proposed self-paced physical exercise to both active and inactive sedentary individuals. Using the Ratings of Perceived Exertion Scale (RPE), we allowed participants to set exercise intensity to their own perception of exertion and contrasted heart rate frequency and power output when comparing Low and High Tolerant individuals. These results confirm previous studies showing that non-athletes men and women are able to self-regulate physical effort on the basis of a score selected on the RPE scale (Carlier, & Delevoye-Turrell, 2017; Coquart, Garcin, Parfitt, Tourny-Chollet, & Eston, 2014; Feriche et al., 1998).

Through the conduction of this methodology, we were able to reveal that Low and High Tolerant individuals possess different self-regulation abilities. More specifically, while High Tolerant constantly increased their power-output, Low Tolerant kept their own constant throughout the 30' session. These results are confirming previous studies indicating that ones' tolerance to exercise is correlated to physical production with more power output produced by those individuals having higher tolerance scores (Carlier et al., 2017; Hall et al., 2014). Our work also confirmed that tolerance effects can be revealed on power output while controlling statistically for self-reported physical activity levels (as evaluated using the IPAQ; Carlier et al., 2017). The replication of the results leads to suppose that individuals' tolerance level may not be entirely related to an individual's motor expertise.

Revealing differences in self-regulation strategies between Low and High Tolerant individuals supports the theoretical model developed by Carlier and Develevoye-Turrell (2017). More specifically, authors suggested that performing a "somewhat difficult" physical activity means performing a motor task going from a low to a high end moderate continuum (Fig. 4). Hence, the constantly increasing Power Output in High Tolerant individuals would mean that these participants are able to support higher levels of discomfort in comparison to what they predicted;

leading them to detect a mismatch, i.e., a level of discomfort smaller than that expected at the beginning of the motor task. Hence, to reduce the discrepancy between true and predicted inner states of discomfort they augmented progressively the intensity of practice until the end of the physical activity. The Low Tolerant group on the other hand may have found a direct match between predicted and true inner states of discomfort leading them to maintain a constant intensity of practice throughout the session, remaining at the low end of the moderate intensity continuum. Strikingly, High and Low Tolerant individuals distinguished themselves progressively during the session by revealing contrasting ways of self-regulating power output. Hence, when reaching the last 5 minutes of the session, distinct profiles characterized our groups of participants as a function of their Tolerance score. The results suggest that during the course of the previous 25 minutes of the session High Tolerant individuals were able to handle both the physical and the cognitive demands of the task leading them to progressively increase Power Output while Low Tolerant individuals were not. The affective states experienced during a session may contribute to the formation of a positive or negative memory trace for exercise, which in turn may influence consciously or subconsciously subsequent decisions to engage in, adhere to or drop out from exercise, (Ekkekakis et al., 2011). In such a case, we can also propose that in order to keep the more positive souvenir of the session and possibly re-exercise, High Tolerant individuals increased the difficulty of the task while Low Tolerant individuals remained their own stable even decreased it.

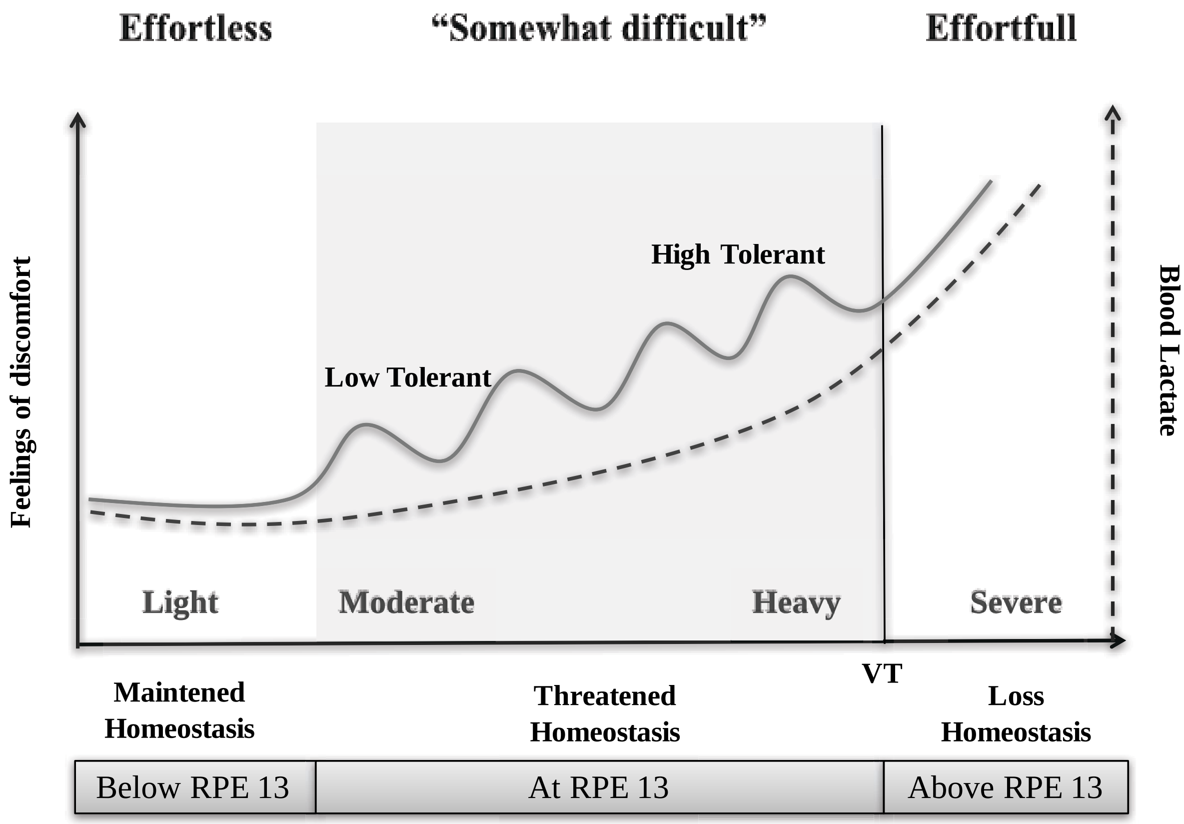


Figure 4. A psycho-physiological framework of Tolerance and Affective states. This conceptual framework illustrates the possible functional association between biological (lactate concentration – not measured here), physiological (Rating of Perceived Exertion – RPE scale) and psychological factors (Feelings of discomfort; Tolerance to effort). Setting the exercise intensity to “moderately difficult” (RPE13), feelings of discomfort will augment with increasing concentrations of lactate in the blood. As a function of one’s tolerance to inner states of sensorial distress, individuals will target different pre-defined levels of acceptable discomfort, which may be used to detect the upcoming loss of homeostasis. Understanding the psychological factors that modulate one’s ability to set and predict correctly one’s tolerable level of sensorial discomfort may help us gain a better understanding of why some like it slow and easy, and others like it vigorous.

During the Experiment 2, we revealed that Low Tolerant individuals are characterised by weaker updating and inhibiting abilities. More specifically, while High Tolerant are characterised by greater working memory span and greater inhibition abilities, especially when following an error, Low Tolerant individuals present less efficient updating and inhibiting abilities. Hence, we can suppose that individuals with weaker executive functions will have weaker resistance to sensorial feelings of discomfort than individuals with more efficient executive functions. As a consequence, Low Tolerant individuals self-paced the physical session at lower intensities than did High Tolerant individuals.

b) Dissociating the Heart Rate Frequency from physical load

Throughout the physical activity session, we revealed that for a same perception of effort High Tolerant individuals were characterised by an increase in Power Output (PO) associated to an increase in Heart Rate Frequency (HRF). However, while Low Tolerant individuals presented the same HRF dynamic compared to High Tolerant individuals, their PO did not increase. Effort is defined as the « amount of mental or physical energy being given to a task » (Abbiss et al., 2015). Then, when asking individuals to perform “somewhat difficult” physical exercise both the physical and the cognitive load of the motor task are taken into account as we observed in Study II. We can thus suppose that the increase in Heart Rate Frequency in Low Tolerant individuals reflects the cognitive difficulties they have to handle during the task instead of reflecting an increase in physical effort.

VII. Conclusion

Individuals Tolerance level may be considered (1) as a neuropsychological concept and (2) a valuable/key psychological factor predetermining the power output during a physical activity session. These differences observed for executive functions can then explain why, in addition to physical differences, High Tolerant individuals are able to tolerate more pain or discomfort in comparison to Low Tolerant individuals. Furthermore, we can suppose that the executive differences observed between Low and High Tolerant individuals may be at the core of their different self-regulation strategies.

What’s next?

Study III revealed different cognitive abilities between High and Low Tolerant individuals whatever their fitness level. Thus, Low Tolerant individuals will have more difficulty in adjusting motor output intensity during practice and risk more easily that High Tolerant individuals to stop over the homeostasis threshold into the red zone. The work in study III offers a simple and new procedure that can be transferred to clinical settings to detect the degree of tolerance of an individual and monitor throughout a session the perceived work load in order to maintain the individual within the somewhat difficult zone. In such a context, the transferability of the experimental design is actually performed in collaboration with the re-education unit “l’Espoir” with patients suffering from stroke (Lille, France).

The limiting methodological point in study III was the fact that using heart rate frequency to infer inner affective states. Hence, in study IV we included a method to monitor both the physiological response and the perceived affective states during practice.

The second major objective of the study IV was to consider how to improve the pleasant experience of a bout of moderate physical exercise. This is important because to reach the flourishment state of well-being, a regular practice of physical exercise needs to be accepted by the practitioners over long period of time. Hence, we conducted a study in which the practice environment was enriched with energizing music. Furthermore, the corollary discharge theory postulate that the way one perceives how much a physical exercise is exhausted can be a function of the environmental condition in which the motor task is performed. Hence the objective of Study IV was to assess how these differences in cognitive strategies would lead to set Low and High Tolerant individuals to live different cycling either in silent or in musical environment.

Study IV

Tolerance to exercise intensity modulates pleasure when exercising in music: the upsides of acoustic energy for high tolerant individuals.

Published in Plos One

Mauraine CARLIER[1] & Yvonne DELEVOYE-TURRELL[1]* on behalf of the Fun2move consortium

[1]SCALab, UMR CNRS 9193, Department of psychology, University of Lille, Lille, France

***** Corresponding author
E-mail: yvonne.delevoye@univ-lille3.fr (YD)

The authors contributed equally to this work.
^Membership of the Fun2move Consortium can be found on the official Internet sight: http://sport-plaisir.univ-lille3.fr

HIGHLIGHTS

1. Fun activities do not always trigger pleasurable affective states
2. Tolerance to effort is a cognitive factor that is independent from fitness level
3. Low tolerant individuals experience increased heart rate when listening to energizing music without gain in physical performance and positive feelings.
4. Tolerance levels must be taken into account when prescribing pleasurable physical activity because it can predict the affective outcome of distracting environments

Abstract

Moderate physical activity can be experienced by some as pleasurable and by others as discouraging. This may be why many people lack sufficient motivation to participate in the recommended 150 minutes of moderately intense exercise per week. In the present study, we assessed how pleasure and enjoyment were modulated differently by one's tolerance to self-paced physical activity.

Sixty-three healthy individuals were allocated to three independent experimental conditions: a resting condition (watching TV), a cycling in silence condition, and a cycling in music condition. The tolerance threshold was assessed using the PRETIE-Questionnaire. Physical activity consisted in cycling during 30 minutes, at an intensity perceived as "somewhat difficult" on the Ratings of Perceived Exertion Scale.

While controlling for self-reported physical activity level, results revealed that for the same perception of exertion and a similar level of enjoyment, the High Tolerance group produced more power output than the Low Tolerance group. There was a positive effect of music for High Tolerant individuals only, with music inducing greater power output and more pleasure. There was an effect of music on heart rate frequency in the Low Tolerant individuals without benefits in power output or pleasure.

Our results suggest that for Low Tolerant individuals, energizing environments can interfere with the promised (positive) distracting effects of music. Hence, tolerance to physical effort must be taken into account to conceive training sessions that seek to use distracting methods as means to sustain pleasurable exercising over time.

I. Introduction

Tolerance to exercise intensity is a trait that influences one's ability to continue exercising at levels of intensity associated with discomfort and displeasure [1]. As much as there are individuals who like vigorous training sessions and will tolerate high sensory stimulation or pain to some extent (the "Feel strong" profile), many inactive individuals will consider engaging in a physical exercise only at a slow and leisure pace to avoid senses of fatigue, exhaustion or breathlessness. For these reasons, distracting methods (using music and videos) have been developed to decrease the perception of exertion and enhance positive affective states and moods during exercise [2,3,4,5]. Nevertheless, in a typical week, 60 % of adults in Europe admit engaging in no physical exercise at all [6]. Worse yet, in the low number of people who choose to initiate a regular program of physical activity, a high rate of dropout has been estimated to be approximately 50 % within the first few months [7]. As pleasure seems to be a key feature in motivating exercising, the aim of this study was to assess the effects of a distracting musical environment on the pleasure and the enjoyment experienced during the practice of self-paced cycling activities in sedentary active and inactive individuals.

The distribution of energy expenditure throughout an exercise task is known as pacing and is extremely important as it predetermines the ability to maintain the intensity of a physical exercise across a given period of time. When prescribing physical exercises for health benefits to inactive individuals, care practitioners need to specify the dosage of exercise as a function of many parameters (e.g., frequency (F), intensity (I), duration (time, T) and type (T) – the FITT principle – [8]). However, intensity is thought to be the most important variable to guide cardiovascular training as exceeding the appropriate intensity leads to discomfort, overexertion and injury, possibly leading one to avoid future activity [9,10,11,12]. Conversely, an intensity that is lower than what is recommended may prevent noticeable health and fitness benefits but can also be boring, causing frustration and again possible dropout. This is why the practice of a moderate physical activity at 75% of VO2 max is proposed as a good pace intensity for health benefit physical exercise and low dropout. However, several studies have now reported that when prescribing moderate intensities of practice on the basis of maximal oxygen uptake, some individuals perceive the physical session as pleasant while others perceive it as unpleasant with significantly less positive feelings [13,14,15]. It has been suggested that these differences in affective responses (pleasant vs. unpleasant) may be due to the nature of the metabolic strain associated with the exercise session [16,17,18], with certain participants using predominantly aerobic sources whereas others require substantial anaerobic supplementation [19].

The point of transition between predominantly aerobic energy production and anaerobic energy production (VT) may be a more appropriate point of reference than VO2max when seeking to prescribe pleasurable activities in inactive populations [19-24]. In fact, according to the dual mode theory, the affective responses to exercise intensity is said to be predicted by the VT transition marker [1,25]. More specifically, below the VT, the aerobic metabolism is predominant. This is the case when exercising at low intensities (below heart rate of 85 bpm). The practitioners will experience positive affect because the body is able to maintain homeostasis, i.e., a constant energy stream for exercise, simply by breaking down carbohydrates and fats through the use of aerobic metabolic processes. However, above the VT, the rate of oxygen consumption is too high and the energy production is not fast enough. Hence, the anaerobic metabolism kicks in accompanied by the appearance of fatigue, muscle burning, and pains that may be perceived as negative affective states. In later years, it has thus become evident that a method to determine the VT intensity must be found.

To date, incremental protocols are often used to determine the VT intensity. However, such a protocol requires practicing until volitional exhaustion, which may not always be accepted by athletes and should be avoided when working with inactive populations [26]. In this context, affective states have been suggested as a possible indicator as they are known to be the primary means by which information about critical disruptions of homeostasis and energy regulations enter consciousness [27-32]. The self-evaluation procedure may help participants to detect slight modulations in inner state homeostasis [1], and hence can be used as benchmark to self-regulate effort intensity during exercise [19,33,34]. On this basis, the Borg Scale of Perceived Exertion is often used to match how hard one *feels and experiences the difficulty of a practice* session [35]. Thus, it is a “relative” scale that starts with “no feeling of exertion” (RPE 6), and ends with “very, very hard” (RPE 20). Moderate activities register 11 to 14 on the Borg scale (“fairly light” to “somewhat hard”), while vigorous activities usually rate a 15 or higher (“hard” to “very, very hard”). In the scientific literature, it has been shown that active healthy individuals and athletes are able to use the RPE as a way to produce different physical efforts [36,37,38]. Moreover, during incremental exercises using production procedures, VT appears when the physical activity is produced and perceived as “somewhat difficult” (RPE 13 on the 6-20 Borg Scale) in active males when running [38] and athletes when cycling [37]. Results obtained by Eston and Williams [36] are interesting as they indicate that non-athlete adults can use the Borg scale to self regulate their physical effort as a function of their inner feelings of exertion. Hence, attention towards inner changes in affective states must be encouraged as it may lead inactive participants to detect the risk of loss of homeostasis right before the aerobic-anaerobic VT transition, providing the means to self-pace exercise intensity throughout a training session [19] and maintain the highest intensity possible with tolerable degrees of physical effort and sensorial discomfort.

The corollary theory is a conceptual cognitive framework that can offer a first level of understanding of how inner sensorial information and affective states linked to physiological changes may be used by the central system to detect the risk of loss of homeostasis [39]. Indeed, the corollary theory suggests that the perception of tolerable discomfort and exertion will depend on the match or the mismatch between (1) a predicted sensory information sent directly from the motor to the sensory areas of the brain and (2) the actual sensory information received by the sensory areas of the brain directly from the body [40]. If the actual level of discomfort corresponds to the acceptable predicted one, the intensity of current practice is maintained. However, in the case of a mismatch, the system will modulate the current intensity to regain a match and to insure sustainable activity at ones' preferred/acceptable pre-set-intensity of practice. Comparing the actual level of discomfort to the acceptable predicted one will lead practitioners to modulate exercise intensity as a function of the signed computed mismatch. It is the case that the Rating of Perceived Exertion Scale (RPE) involves the collective integration of afferent feedback to enable an individual to evaluate how hard or easy an exercise task feels at any given point in time [41]. Hence, self-evaluation scales implicitly lead individuals to orient attention to those prediction errors made upon the predicted changes in inner sensorial states, targeting as much the positive self-awareness of being, than the negative senses of fatigue, muscle strain and heart pounding.

When considering individuals who possess similar physiological capacities, studies have reported that participants will select a wide range of exercise intensities when tested in self-paced protocols [33, 42]. For example, Lind, Joens-Matre, and Ekkekakis [33] observed that middle-aged, healthy but sedentary women selected intensities varying from as low as 60 % to as high as 160 % of maximal oxygen uptake as identified from a previous graded-volitional exhaustion treadmill test. Variability in these self-paced intensities of practice may be due to heritable variations in pain sensitivity and tolerance [43] but also in the predicted levels of acceptable sensory stimulations [44,45]. Thus, some individuals will set higher thresholds of practice intensities because they predict liking vigorous training sessions and hence, predict that they will tolerate high sensory stimulations associated to pain and heart rate pounding, while others will prefer intuitively engaging in a physical exercise at a low intensity to minimize discomfort, body temperature and heart rate increases.

The corollary theory postulates also that the environment will influence body states and as such, will influence the actual sensory information that the brain truly receives [39]. Thus, modified environments, e.g., presence or absence of music, will possibly modulate the mismatch error between predicted and actual perceived sensory afferences. Music has an entrainment effect that has been well documented in the past ten years. The Embodied Music Cognition model [46], for example, describes how music and specifically, the groove effect can increase body rhythmicity [47] and modulate body posture [48]. Thus, individuals who tolerate high sensory stimulations may experience as pleasant a physical practice in a musical environment while for others, practicing in such condition could be more challenging than practicing in silence, because of being entrained to cycle at a greater intensity than that expected.

In the present study, the working hypothesis is that for similar self-reported physical activity levels, Low Tolerant individuals will have weaker resistance to sensorial feelings of discomfort than High Tolerant individuals and thus, will self-pace the physical session at lower intensities. We also hypothesised that the distracting effects of music will be similar in Low and High Tolerant individuals. Through the entrainment effects of music, all practitioners should increase exercise intensity. However, unlike the High Tolerant individuals, the music will lead Low Tolerant individuals to exercise outside of their comfort zone and report unpleasant affective states even if practicing within an enjoyable environment. In addition, due to the distracting effects of music, Low Tolerant practitioners may miss the cues indicating the loss of homeostasis benchmark that is critical to offer the feel-good experience of physical exercise.

II. Materials and Methods

a) Participants

A total of 68 subjects volunteered to take part in the study but only 63 subjects came (M_{age} = 22,85 ± 4,78 years, M_{BMI} = 24,89 ± 5,76 kg.m-^{2}). Forty-one women and 22 men were allocated to three independent experimental conditions. All subjects obtained a medical certificate from their medical physicians. Before the beginning of the study, each volunteer read an information letter and completed a written consent form. The study was approved by the Ethics Committee for behaviour human studies of the University of Lille. Participants were asked not to participate in any physical training 48 hours before their inclusion.

b) Procedure and questionnaires

The level of self-reported physical activity level was assessed using the International Physical Activity Questionnaire (IPAQ – [49]). After reading and completing the consent form, a heart rate monitor (Polar Team² - Polar Electro Oy, Kempele, Finlande) was fitted to the participants' chest and heart rate was recorded during 15 minutes at rest, and throughout the experimental session. After measuring mean heart rate at rest, participants were asked to complete a series of questionnaires in order to obtain socio-demographic data as well as an overall description of tolerance and pleasure. A testing diagram is presented in Fig 1 to illustrate the experimental design.

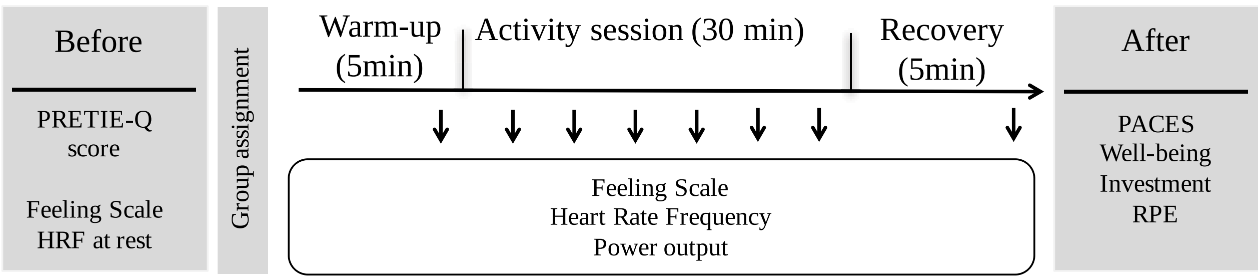


Figure 1. Testing diagram to specify the experimental design that was used in the present study. The different measures taken before, during and after are specified.

Self-reported physical activity level assessment [49]. The IPAQ (International Physical Activity Questionnaire) was used to assess the amount of physical activity practiced by our participants. The quantity of physical activity practiced by each participant was calculated by considering the intensity of the reported physical activity sessions (expressed in METs – Metabolic Equivalent of Task – for 3 different categories: low vs. moderate vs. vigorous) as a function of duration (time in minutes) and of the number of days declared per week (METs-minute/week). The feature of this questionnaire is to consider the overall self-reported physical activity level (including daily activities) and not only the physical activity practiced during leisure sports time. Four different measures were obtained: (1) the Total Physical Activity score, which contains the total amount of physical activity practiced (e.g. METs-minute/week$_{\text{Low}}$, METs-minute/week$_{\text{Moderate}}$ and METs-minute/week$_{\text{Vigorous}}$), (2) the Total Low Physical Activity score, (3) the Total Moderate Physical Activity score and (4) the Total Vigorous Physical Activity score.

Preference for and Tolerance to the Intensity of Exercise Questionnaire *(French version* [1]*)*. The PRETIE-Q was used to assess the variables of preference for and tolerance to exercise intensity. The eight-item Tolerance scale contained four items that targeted high exercise tolerance (e.g. ‘‘I always push through muscle soreness and fatigue when working out’’) and four that targeted low exercise tolerance (e.g. ‘‘During exercise, if my muscles begin to burn excessively or if I find myself breathing very hard, it is time for me to ease off’’). Each item was composed of a 5-point response scale (1 = ‘‘I totally disagree’’; 2 = ‘‘I disagree’’; 3 = ‘‘Neither agree or disagree’’; 4 = ‘‘I agree’’; 5 = ‘‘I strongly agree’’). A high score of tolerance to exercise corresponds to a high capacity to pursue the physical activity although it becomes uncomfortable or unpleasant [1]. To obtain two contrasting groups, a median tolerance score was calculated across all experimental groups. Participants with scores lower than the median (27) were considered as Low Tolerant; individuals with scores greater than the median were classified as High Tolerant. After assessing tolerance level, participants were assigned to three independent experimental conditions: a resting TV condition, a cycling in silence condition or a cycling in music condition. In the resting TV condition, there were 10 Low Tolerant individuals and 5 High Tolerant individuals. Both in the cycling in silence and the cycling in music conditions, there were 12 High Tolerant individuals and 12 Low Tolerant individuals.

Feeling Scale [50] was used to assess the changes in affective states (pleasure / displeasure). This scale consists in a 11-point, single-item, bipolar scale, used for the assessment of affective responses during exercise. The scale ranges from −5 to +5. Anchors are provided at zero, and at all odd integers (+5 = very good; +3 = good; +1 = fairly good; 0 = neutral; −1 = fairly bad; −3 = bad; −5 = very bad).

Physical Activity Enjoyment Scale [51]. The PACES was administered 10 minutes after the end of the experimental session. The questionnaire is composed of 10 items following a 7-point bipolar scale (e.g., *I dislike it – I like it*). Higher scores reflect greater levels of enjoyment. The PACES items were adapted in order to also be used in the resting TV condition.

Investment assessment was achieved using a 9-point, bipolar scale that was created to get a feel of how much practitioners felt involved in the task. Participants were asked 10 minutes after the end of the session whether they felt to have been invested in the activity, cognitively and physically. The scale ranged from -4 to +4. Anchors are provided at zero and at all even integers (-4 = not at all; -2 = hardly; 0 = neutral; +2 = a lot; +4 = to a large degree).

Well-being assessment. The 5-point SAM Scale was used to assess the state of well-being 10 minutes after the end of the experimental session. Participants were simply asked whether they felt that the session had done them good (e.g., *Yes-I totally agree - No-I totally do not agree*).

Perception of exertion assessment [35]**.** The Ratings of Perceived Exertion was used 10 minutes after the end of the experimental session to verify that participants considered having done a “somewhat difficult” physical activity throughout the session (RPE 13 on the 6-20 Borg Scale).

c) Experimental conditions

Following the scores obtained in the PRETIE-Q questionnaire, participants were evenly assigned to three independent experimental conditions: a resting TV condition, a cycling in silence or a cycling in music condition.

In the resting TV condition, participants watched a 40-minute TV documentary relative to newly discovered civilization in Egypt [52]. This experimental condition was chosen in order to control whether the tolerance level may have an impact on the cardiac frequency and affective states and their dynamics throughout a 40-minute period of watching a screen. In the two cycling conditions, participants performed 40 minutes of physical activity. Three phases were proposed: the warm-up (5 minutes), the physical activity (30 minutes), and the recovery periods (5 minutes) – following criterion described in ACSM [8].

For all three experimental conditions, changes in the affective states were assessed using the Feeling Scale (FS). In the cycling conditions, the FS was administered before warm up, after warm-up, and every 5 minutes during the practice phase. Thus, nine periods were identified: one before warm-up (0'), one after warm-up (5’), six during the test (10', 15', 20', 25', 30’, 35’), and one after recovery (40'). For all participants, debrief was systematically conducted after the experimental session to explain the aims and the construct of the study.

In the two physical activity conditions, the participants pedalled an electronically ergo-cyclometer (EXC NewBike 700SP, Technogym, Italy). A picture of a path through a forest was projected on a screen (195 cm x 280 cm) placed 250 cm in front of the participants. Pleasant light was also proposed to optimize the pleasant experience of the physical activity [53]. During the warm-up phase, participants were asked to pedal at a speed that would allow them to warm-up and to become familiar with the ergo-cyclometer. During the physical activity (30 min), participants were required to pedal at a speed that they felt as "somewhat difficult" on the Borg RPE scale (RPE 13 on the 6-20 Borg Scale). The power-output (PO) and the heart rate frequency (HRF) produced during the three phases were also measured every minute. Nevertheless, for the statistical analyses, PO and HRF were resampled at one sample every 5 minutes.

To create a more pleasurable environment, music was chosen by the participants amongst four "Sport" playlists that were downloaded from the music streaming platform *Spotify*: “motivation for sports”, “power workout”, “cardio” and “sports”. For the warm-up and the recovery phases, music was downloaded from the playlist “Keep calm and stretch it”. A stereo system was used and set at a comfortable sonic level for each individual (Yamaha hs 8). The properties of these audio playlists are available as supplementary materials (S1 Table).

KEEP CALM	Tempo	Energy	Groove	Duration	Mode	Valence
CalmingMusic	66.014	0.125661	0.202002	299.12644	1	0.03312
MinimalSteps	98.031	0.088988	0.507274	330.71002	1	0.054884
Dreamers	140.013	0.058212	0.572493	201.86063	1	0.039156
BlankSpaceFocus	89.986	0.083598	0.37934	261.55868	1	0.037322
Balance	66.751	0.105551	0.200186	282.72729	0	0.037199

SPORTS	Tempo	Energy	Groove	Duration	Mode	Valence
Domino	126.993	0.531467	0.7753	200.82667	1	0.882473
LoseYourself	171.387	0.762663	0.689181	326.64	1	0.060821
Happy	120.129	0.660274	0.716196	263.49601	1	0.351701
Stronger	108.495	0.591883	0.411862	246.10667	1	0.35792
HeyBrother	125.012	0.790496	0.525328	206.67955	0	0.472574

MOTIVATION	Tempo	Energy	Groove	Duration	Mode	Valence
EyeoftheTiger	108.72	0.377376	0.830521	250.8	0	0.619104
LightItUp	107.985	0.87694	0.745646	166.13823	0	0.761805
GoodFeeling	128.006	0.853962	0.704754	247.97333	0	0.679432
Timber	130.014	0.94247	0.586827	203.42667	1	0.799888
YoureOn	100.1	0.866125	0.47379	171.97288	0	0.30379

CARDIO	Tempo	Energy	Groove	Duration	Mode	Valence
LoveMyself	122.909	0.760651	0.619438	218.77333	0	0.319986
Beverly	102.988	0.504205	0.935589	200.38834	1	0.746023
SunglassesRemix	117.992	0.937084	0.738041	221.69447	1	0.843092
Sax	117.981	0.855602	0.716741	219.54753	1	0.871007
Backbeat	139.932	0.879355	0.707123	227.09492	0	0.681927

WORKOUT	Tempo	Energy	Groove	Duration	Mode	Valence
CheapThrills	89.976	0.698268	0.628313	211.66667	0	0.730264
Sorry	99.992	0.759459	0.664727	200.78667	0	0.382132
YOUTH	91.522	0.74946	0.626575	185.19401	1	0.565315
CantFeelMyFace	107.954	0.781735	0.713659	216.46667	0	0.586261
SomethingSweet	99.979	0.790709	0.621856	195.56	0	0.657068

S1 Table: Sonic properties of the audio playlists that were used in the cycling in music condition

III. Statistical analyses

ANCOVAs were conducted to reveal main effects of Experimental Condition (Resting, Cycling in silence versus Cycling in music) and Tolerance Level (High versus Low Tolerant) while controlling for the self-reported physical activity level: (1) on general demographics; (2) on the mean scores of PACES and Well-Being; (3) on the mean scores of the perception of exertion scale and the sense of investment felt in the two physical activity conditions. In the resting TV condition, we conducted a mixed model ANCOVA with Tolerance Level (High versus Low Tolerant) as independent factor and Assessment Time (8) as repeated factor, while controlling for the self-reported physical activity level. In the two cycling conditions, mixed Model ANCOVAs were conducted to determine effects of Experimental Condition (Cycling in silence versus Cycling in music), Tolerance Level (2) and Assessment Time (8) on Feeling Scale (FS), Heart Rate Frequency (HRF) and Power Output (PO), while controlling for the self-reported physical activity level. For the FS and HRF variables, baseline values were systematically included within the statistical model as covariates. Throughout these analyses, partial eta squares (η^2_p) were calculated to report the effect sizes. Bonferroni-adjusted pairwise comparisons were used when required for the post-hoc analyses.

IV. Results

a) Group demographics

The participants that were allocated to the three independent experimental Conditions did not differ in Age ($F(2,59) = 1.473$; $p = 0.237$), Body Mass Index ($F(2,59) = 0.465$, $p = 0.630$), Educational Level ($F(2,59) = 1.467$, $p = 0.239$). No group effects were observed for the IPAQ scores obtained on the dimensions Total Physical Activity ($F(2,61) = 0.637$; $p = 0.532$), Total Low ($F(2,61) = 0.686$; $p = 0.507$), Total Moderate ($F(2,61) = 0.594$; $p = 0.555$) and Total Vigorous Physical Activity ($F(2,61) = 0.867$ $p = 0.425$). There was an absence of Tolerance effects on all demographics. Further descriptive results are presented as supplementary material in S2-S3 Tables.

	Resting Group (N=15)	Cycling Group (N = 24)	Cycling in music Group (N = 24)	Statistical analysis
Age (y)	22,8 (6,92)	24,09 (4,21)	21,7 (3,43)	F(2,59) = 1.473; p = 0.237
Body mass index (kg.m^{-2})	23,64 (4,35)	25,38 (5,25)	25,2 (6,98)	F(2,59) = 0.465, p = 0.630
Educational Level (years)	2,6 (1,5)	3,35 (1,43)	2,67 (1,73)	F(2,59) = 1.467, p = 0.239
Tolerance Score	26,13 (6,78)	26,75 (4,05)	26,63 (4,32)	F(2,60) = 0.077, p = 0.926
Repartition of men and women	Men : N= 4 Women : N= 11	Men : N= 9 Women : N= 15	Men : N= 9 Women : N= 15	F(2,60) = 0.441, p = 0.646
Repartition of Low and High Tolerant to exercise	Low : N= 10 High : N= 5	Low : N= 12 High : N= 12	Low : N= 12 High : N= 12	F(2,60) = 0.829, p = 0.441.

S2 Table: Demographics. Reports the descriptive results for Age (years), Body Mass Index (kg.m^{-2}), Educational Level (number of years after Baccalauréat), Tolerance Score, Repartition of men and women, and Repartition of Low and High Tolerant to exercise as a function of experimental conditions.

	Resting Group (N=15)	Cycling in silence (N = 24)	Cycling in music (N = 24)	Statistical analysis
Total Low Physical Activity (METs-minutes/week)	1087 (812)	757 (688)	905 (1014)	F(2,61) = 0.686; p = 0.507
Total Moderate Physical Activity (METs-minutes/week)	457 (340)	617 (734)	751 (1079)	F(2,61) = 0.594; p = 0.555
Total Vigorous Physical Activity (METs-minutes/week)	944 (1366)	1145 (1391)	1641 (2224)	F(2,61) = 0.897 p = 0.425
Total Physical Activity Practiced (METs-minutes/week)	2488 (1594)	2520 (1813)	3298 (3789)	F(2,61) = 0.637; p = 0.532

S3 Table: Fitness level. Descriptive results for the quantitative amount of physical activity practiced as a function of experimental group (METs: Metabolic Equivalents - a useful, convenient and standardized way to describe the absolute intensity of a variety of physical activities - ACSM, 2014).

b) Results for the individuals watching TV

Baseline measures. No main effects of Tolerance Level were found neither on the FS (F(1,12) = 1.532, p = 0.240) nor on the HRF (F(1,8) = 1.235, p = 0.299). Hence, the Low and the High Tolerance groups were similar concerning their affective states and their heart rate frequency before the start of the TV session. *Session measures.* Tolerance Level main effects were revealed neither on the FS (F(1,11) = 1.133, p = 0.309) nor on the HRF (F(1,7) =1.949, p = 0.205). No Assessment Time effects were revealed on the FS (F(7,77) = 1.329, p = 0.248). An Assessment Time effect was found on the HRF (F(7,49)= 2.286, p = 0.043, η^2_p = 0.25): HRF was higher at the start (M_{HR} = 86.4 bpm; *SD* = 13.9 bpm) than at the end of the session (M_{HR} = 76.3 bpm; *SD* = 9.9 bpm). The interaction Assessment Time x Tolerance Level reached significance neither on the FS (F(7,77) = 0.235, p = 0.975) nor on the HRF (F(7,49) = 1.250, p = 0.295).

	Warm up period				Physical activity at RPE 13 period				Recovery Period			
	F	***df***	***p***	η^2_p	***F***	***df***	***p***	η^2_p	***F***	***df***	***p***	η^2_p
Main effects												
Feeling Scale												
Experimental Condition effect	0.141	1,42	0.709	0.00	0.718	1.42	0.402	0.02	2.17	1,42	0.148	0.05
Tolerance effect	0.201	1,42	0.656	0.00	0.014	1.42	0.908	0.00	1.069	1,42	0.307	0.02
Assessment Time	-	-	-	-	0.257	5.210	0.935	0.00	-	-	-	-
Heart Rate Frequency												
Experimental Condition effect	0.567	1,30	0.457	0.02	1.414	1.30	0.244	0.05	5.808	1,30	**0.022**	0.16
Tolerance effect	1.816	1,30	0.187	0.06	0.734	1.30	0.398	0.02	0.006	1,30	0.938	0.00
Assessment Time	0.388	4,120	0.817	0.01	0.907	5.150	0.478	0.03	0.373	4,120	0.827	0.01
Power Output												
Experimental Condition effect	3.469	1,43	0.069	0.07	2.536	1.43	0.118	0.06	5.971	1,43	**0.018**	0.12
Tolerance effect	0.477	1,43	0.493	0.01	5.107	1.43	**0.028**	0.11	4.821	1,43	**0.033**	0.10
Assessment Time	4.599	4,172	**0.001**	0.10	3.634	5.215	**0.004**	0.08	7.368	4,172	**<.001**	0.15
Interactions effects												
Feeling Scale												
Experimental Condition*Tolerance	0.939	1,42	0.337	0.02	4.161	1.42	**0.047**	0.09	5.304	1,42	**0.026**	0.11
Assessment Time*Experimental Condition	-	-	-	-	0.631	5.210	0.675	0.01	-	-	-	-
Assessment Time*Tolerance	-	-	-	-	1.946	5.210	0.088	0.04	-	-	-	-
Assessment Time*Experimental Condition*Tolerance	-	-	-	-	0.139	5.210	0.983	0.00	-	-	-	-
Heart Rate Frequency												
Experimental Condition*Tolerance	0.683	1,30	0.415	0.02	0.15	1.30	0.701	0.00	0.298	1,30	0.589	0.00
Assessment Time*Experimental Condition	1.342	4,120	0.258	0.04	3.786	5.150	**0.003**	0.11	0.943	4,120	0.442	0.03
Assessment Time*Tolerance	1.146	4,120	0.338	0.04	0.697	5.150	0.626	0.02	1.618	4,120	0.174	0.05
Assessment Time*Experimental Condition*Tolerance	0.621	4,120	0.648	0.02	1.287	5.150	0.273	0.04	1.723	4,120	0.149	0.05
Power Output												
Experimental Condition*Tolerance	0.746	1,43	0.392	0.02	1.094	1.43	0.301	0.02	0.587	1,43	0.447	0.01
Assessment Time*Experimental Condition	0.914	4,172	0.457	0.02	0.462	5.215	0.804	0.01	2.992	4,172	**0.020**	0.07
Assessment Time*Tolerance	1.114	4,172	0.352	0.03	5.83	5.215	**<.001**	0.12	0.146	4,172	0.964	0.00
Assessment Time*Experimental Condition*Tolerance	0.613	4,172	0.654	0.01	3.599	5.215	**0.004**	0.08	1.288	4,172	0.276	0.03

Table 1: Overall statistical results for the main effects and the interactions on Feeling scale, Heart Rate Frequency and Power Output as a function of Assessment period, Experimental Condition and Tolerance group.

c) Results for the individuals cycling in silence and in music

Baseline measures. The main effect of Condition was revealed significant neither for the FS ($F(1,43) = 2.948$, $p = 0.093$) nor for the HRF ($F(1,31) = 0.157$, $p = 0.694$). No Tolerance Level main effects were found for the FS ($F(1,43) = 0.249$, $p = 0.620$) nor for the HRF ($F(1,31) = 0.006$, $p = 0.937$). No Condition x Tolerance Level interaction was found for the FS ($F(1,43) = 0.004$, $p = 0.947$) and for the HRF ($F(1,31) = 4.006$, $p = 0.054$). Hence, the Low and the High Tolerance groups were similar concerning their affective states and their heart rate frequencies before the start of practice both in the cycling in silence and the cycling in music conditions.

Warm-up measures. The measures taken on the FS during this period revealed an absence of main effects both for Condition and Tolerance Level. Similar absence of effects was revealed also for the HRF. Statistical results are presented in Table 1. For the PO, an Assessment Time effect was revealed ($F(4,172) = 4.599$, $p = 0.001$, $\eta^2_p = 0.10$): the PO was greater at the end ($M_{Power\text{-}output} = 52.46$ watts, $SD = 23.9$ watts) than at the start of the warm-up period ($M_{Power\text{-}output} = 47.07$ watts, $SD = 21.1$ watts). No other effects were significant.

Practice measures. Participants were required to cycle at moderate level (RPE 13) for a total period of 30 minutes. When considering the mean FS scores, results revealed an absence of main effects for Condition, Tolerance Level and Assessment Time (Table 1). However, the interaction Condition x Tolerance Level was significant ($F(1,42) = 4.161$, $p = 0.047$, $\eta^2_p = 0.09$). The Low Tolerance groups revealed similar scores on the FS whether cycling in music ($M_{Feeling\ Scale} = 2.53$, $SD = 1.58$) or in silence ($M_{Feeling\ Scale} = 2.63$,

SD = 0.89) (p = 0.846). On the other hand, in the High Tolerant groups, greater FS scores were observed in the cycling in music condition ($M_{Feeling\ Scale}$ = 3.14, SD = 0.89) than in the cycling in silence condition ($M_{Feeling\ Scale}$ = 2.13, SD = 1.37) (p = 0.051) (Fig 2-*left*).

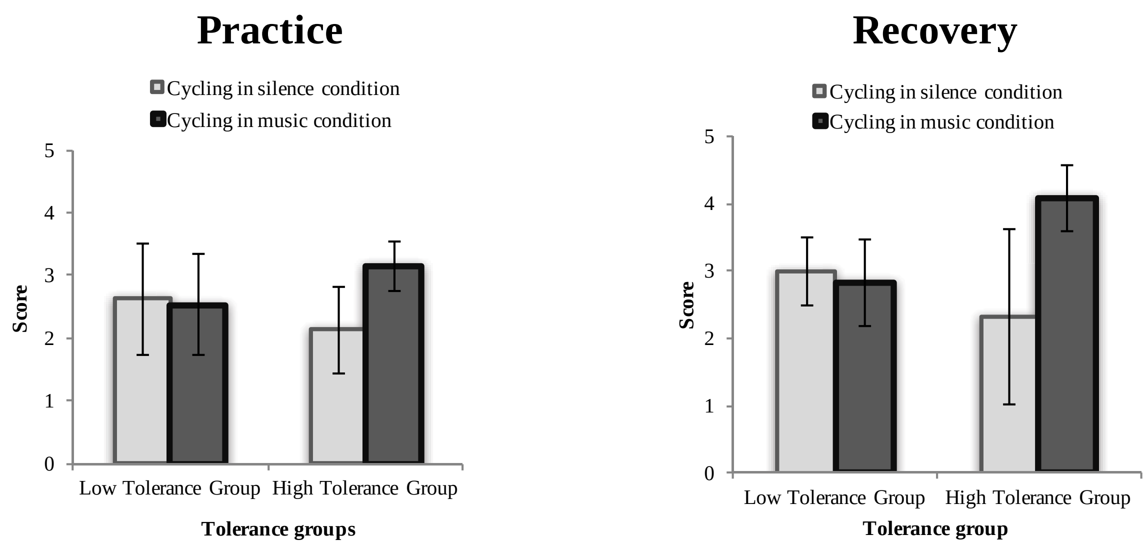


Figure 2. Scores obtained on the Feeling Scale (FS) in the High and Low Tolerance groups during the practice phase (*left*) and the recovery phase (*right*) as a function of the experimental condition (cycling in silence and cycling in music).

When considering the HRF, results revealed an absence of main effects of Condition, Tolerance Level and Assessment Time. However, the interaction Assessment Time x Condition was highly significant ($F(5,150) = 3.786$, $p = 0.003$, $\eta^2_p = 0.11$). For both the Low and High Tolerance groups, HRF increased faster for individuals in the cycling in music condition compared to participants in the cycling in silence condition (Fig 3). In the cycling in music condition, pairwise comparisons revealed greater differences when comparing HRF at different times during the session than in the cycling in silence condition (S4 Table for more details).

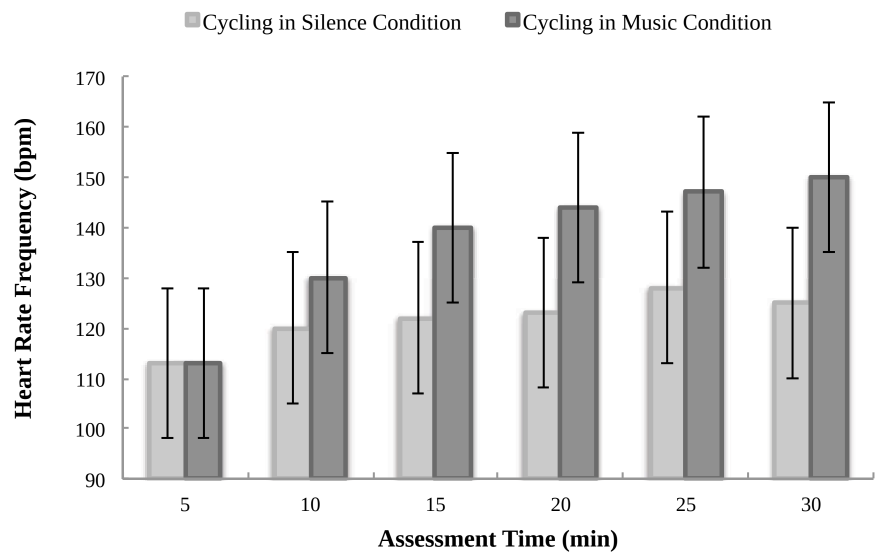


Figure 3. Variations in heart rate frequency as a function of Assessment Time in the cycling in silence condition (*grey*) and the cycling in music condition (*black*). Error bars illustrate the confidence intervals 95% around the mean.

For the PO, there was no main effect of Condition but the main effect of Tolerance Level was significant ($F(1,43) = 5.107$, $p = 0.028$, $\eta^2_p = 0.11$): the High Tolerance group produced more power output ($M_{Power\text{-}output} = 88.81$ watts, $SD = 32.42$ watts) than the Low Tolerance group ($M_{Power\text{-}output} = 70.43$ watts, $SD = 23.13$ watts). An Assessment Time effect was also observed ($F(5,215) = 3.634$, $p = 0.004$, $\eta^2_p = 0.08$): the PO was greater at the end ($M_{Power\text{-}output} = 81.98$ watts, $SD = 39.5$ watts) than at the start of the practice phase ($M_{Power\text{-}output} = 76.33$ watts, $SD = 28.38$ watts). The interaction effect between Assessment Time and Tolerance Level was also significant ($F(5,215) = 5.833$, $p < 0.001$, $\eta^2_p = 0.12$). Pairwise comparisons confirmed significant differences between the High Tolerance group and the Low Tolerance group at 10’ ($Delta_{means}$ = 17.42, SE = 7.8, p = 0.031), at 15’ ($Delta_{means}$ = 16.75, SE = 8.36, p = 0.051), at 20’ ($Delta_{means}$ = 19.29, SE = 8.46, p = 0.028) and at 30’ ($Delta_{means}$ = 32.13, SE = 10.11, p = 0.003) of the physical session, with the High Tolerance group producing always more PO than the Low Tolerance group. Results also revealed in the High Tolerance group significant differences between PO at 30’ and at 5’ of practice ($Delta_{means}$ = 14.38, SE = 4.28, p = 0.019), with more physical output produced at 30’.

Finally, for the PO, the triple interaction Assessment Time x Condition x Tolerance Level was significant (F(5,215) = 3.599, p = 0.004, η^2_p = 0.08). Results are presented in Fig 4. In the High Tolerance group cycling in music, the PO observed at 30’ of practice differed from that observed at 5’ ($Delta_{means}$ = 22.92, SE = 6.05, p = 0.007), at 10’ ($Delta_{means}$ = 20.08, SE = 5.49, p = 0.010) and at 15’ ($Delta_{means}$ = 18.08, SE = 5.47, p = 0.029), with always more power output produced at 30’ compared to the other assessment times. Post-hoc analyses also confirmed differences between the High Tolerance group and the Low Tolerance group in the cycling in music condition at 20’ ($Delta_{means}$ = 25.75, SE = 11.97, p = 0.037), at 25’ ($Delta_{means}$ = 28.42, SE = 13.34, p = 0.039) and at 30’ ($Delta_{means}$ = 49.83, SE = 14.3, p = 0.012). For the High Tolerance groups only, post-hoc analyses across conditions revealed differences between cycling in music and cycling in silence condition at 25’ ($Delta_{means}$ = 27.33, SE = 13.34, p = 0.047) and at 30’ ($Delta_{means}$ = 33.92, SE = 14.29, p = 0.022), with always more PO produced when cycling in music compared to cycling in silence condition (S5 Table for more details).

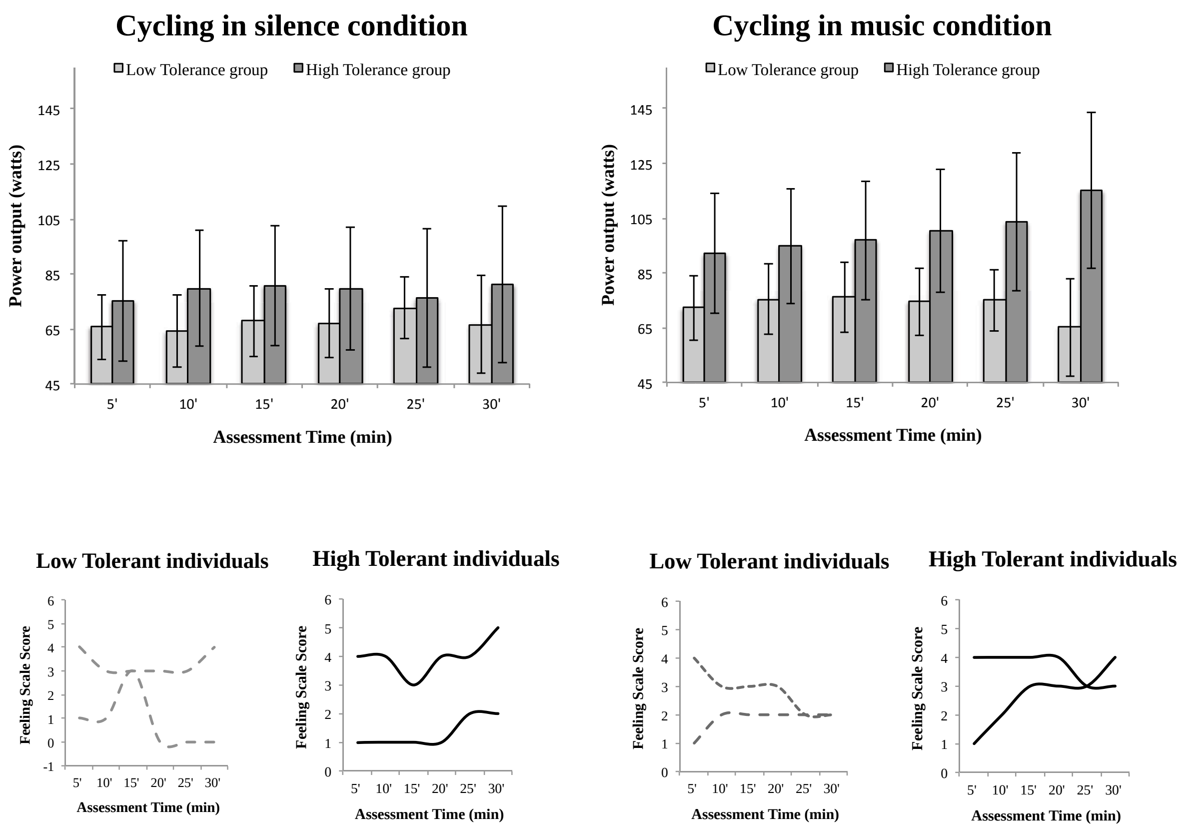


Figure 4. Variations in power output and Feeling Scale. Variations in power output (*Top*) as a function of Assessment Time for the Low Tolerance groups (*grey*) and the High Tolerance groups (*black*) in the cycling in silence condition (*left*) and the cycling in music condition (*right*). Error bars illustrate the confidence intervals 95% around the mean. Scores obtained on the Feeling Scale throughout the 30' exercise session are presented (*Bottom*) for 8 typical individuals in order to illustrate the non-linearity of the modulations in affective states, whether cycling in silence or in music.

Recovery measures. When considering the FS, neither the main effect of Condition nor the main effect of Tolerance Level was significant (Table 1). The interaction Condition x Tolerance Level reached significance ($F(1,42) = 5.304$, $p = 0.026$, $\eta^2_p = 0.11$; Fig 2-*right*). The Low Tolerance groups were characterized by similar scores on the FS whether cycling in music ($M_{Feeling\ Scale} = 2.83$, $SD = 1.27$) or in silence ($M_{Feeling\ Scale} = 3$, $SD = 1$) ($p = 1.00$). On the other hand, the High Tolerant individuals in the cycling in music condition presented greater FS scores ($M_{Feeling\ Scale}$ = 4.08, *SD* = 1) than the High Tolerant individuals in the cycling in silence condition ($M_{Feeling\ Scale}$ = 2.33, *SD* = 2.06) (p = 0.008).

When considering the HRF, no main effects of Condition, Tolerance Level and Assessment Time reached significance. No interactions were found (Table 1).

When considering the PO, results revealed a main effect of Assessment Time (F(4,172) = 7.368, $p < 0.001$, $\eta^2_p = 0.15$), indicating that for all experimental conditions the PO was lower at the end ($M_{Power\text{-}output}$ = 35.67 watts, *SD* =20.27 watts) than at the start of the recovery phase ($M_{Power\text{-}output}$ = 41.41 watts, *SD* = 27.98 watts).

d) Perception of physical effort and investment after practice

When subjects were asked to score their levels of effort, there was an absence of differences between the High and Low Tolerance groups (F(1,35) = 0.159, p = 0.693). In addition, the effect of Condition (F(1,35) = 0.013, p = 0.911) and the interaction Condition x Tolerance Level did not reach significance (F(1,35) = 0.150, p = 0.701). When asked to score their feelings of investment, there was also an absence of mean differences between the High and Low Tolerance groups (F(1,43) = 0.067, p = 0.797). Individuals felt to be invested in the same way both when cycling in silence and when cycling in music (F(1,43) = 1.026, p = 0.317), whether considered as High or Low tolerant individuals (F(1,43) = 2.364, p = 0.131).

e) Enjoyment and Well-being

The PACES enjoyment results revealed a significant effect of Condition (F(2,56) = 3.659; p = 0.032, η^2_p = 0.12), with the cycling in music condition having reported greater levels of enjoyment than the resting TV condition (Fig *5-left*). Neither the main effect of Tolerance Level (F(1,56) = 1.104; p = 0.298) nor the interaction Condition x Tolerance Level (F(2,56) = 0.482; p = 0.620) were significant. The well-being results revealed a main effect of Condition (F(2,56) = 7.207; p = 0.002, η^2_p = 0.20) with the cycling in music condition and the cycling in silence condition reporting greater levels of well-being than the resting TV condition (Fig *5-right*). Neither the main effect of Tolerance Level (F(1,56) = 0.972; p = 0.328) nor the interaction Condition x Tolerance Level (F(2,56) = 1.539; p = 0.223) reached significance.

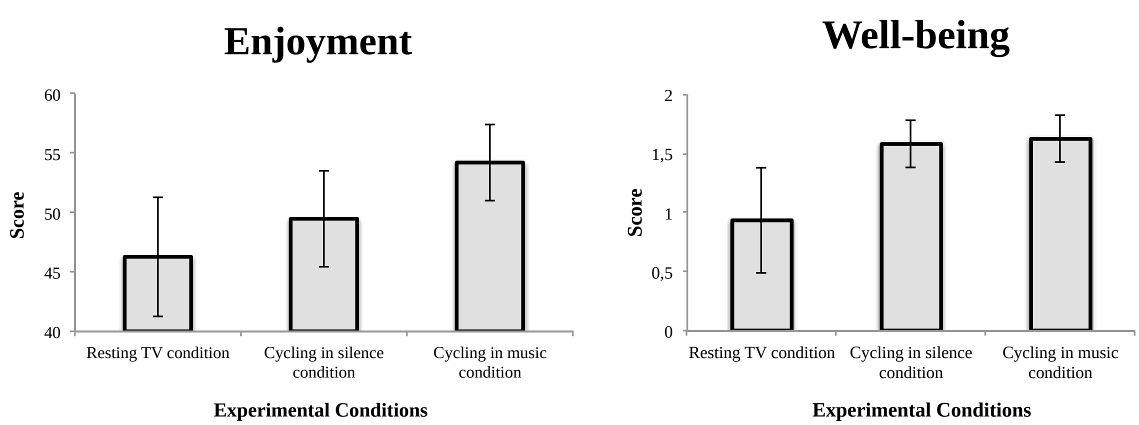


Figure 5. Scores of enjoyment (*left*) and well-being (*right*) are presented as a function of the experimental condition: resting TV condition, cycling in silence and cycling in music conditions. Mean results for the Low and High Tolerance groups are presented to illustrate the absence of group effect.

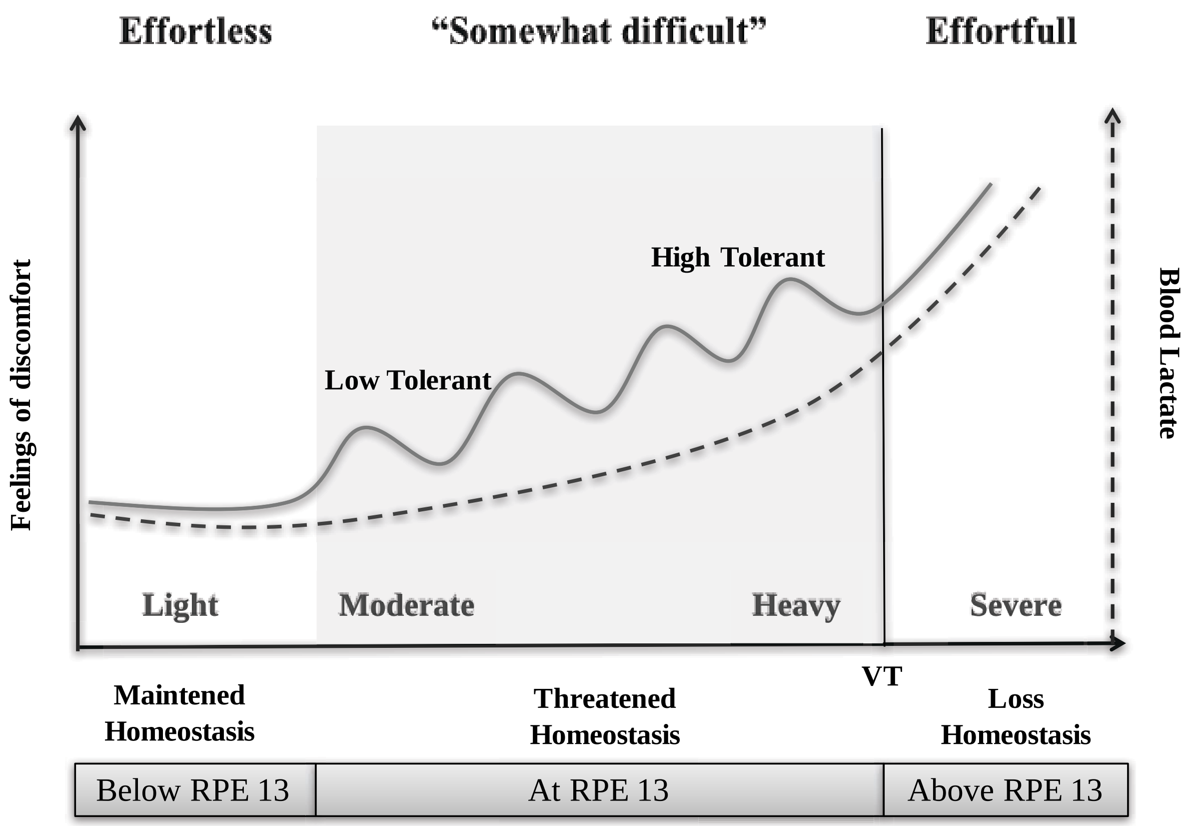


Figure 6. A psycho-physiological framework of Tolerance and Affective states. This conceptual framework illustrates the possible functional association between biological (lactate concentration – not measured here), physiological (Rating of Perceived Exertion – RPE scale) and psychological factors (Feelings of discomfort; Tolerance to effort). Setting the exercise intensity to "moderately difficult" (RPE13), feelings of discomfort will augment with increasing concentrations of lactate in the blood. As a function of one's tolerance to inner states of sensorial distress, individuals will target different pre-defined levels of acceptable discomfort, which may be used to detect the upcoming loss of homeostasis. Understanding the psychological factors that modulate one's ability to set and predict correctly one's tolerable level of sensorial discomfort may help us gain a better understanding of why some like it slow and easy, and others like it vigorous.

V. Discussion

In the present study, we proposed a self-paced cycling activity to both active and inactive sedentary individuals. Using the Ratings of Perceived Exertion Scale (RPE), we allowed participants to set exercise intensity to their own perception of exertion and contrasted power output and affective states when participants were cycling in silence and cycling in music. The main results of our work showed that both High and Low Tolerant participants reported to have (1) exercised at a moderate intensity felt as « somewhat difficult », i.e., RPE 13 on the 6-20 Borg Scale and (2) invested the task at a similar degree of implication. Thanks to the use of a control condition during which participants cycled in silence, we confirmed that the RPE scale can be used as a subjective guide to gauge exercise intensity both by High and Low Tolerant individuals as they self-paced the cycling activity to produce similar levels of power output, at the beginning of the session. These results confirm previous studies showing that non-athletes men and women are able to self-regulate physical effort on the basis of a score selected on the RPE scale [37,26]. However, it is during the course of the physical practice that differences between the two groups of participants emerged.

a) Predicting acceptable intensity of practice

Our results showed that High Tolerant participants were characterised by greater power output compared to the Low Tolerant individuals throughout the 30-min exercise session, confirming again previous studies indicating that ones' tolerance to exercise is correlated to physical production with more power output produced by those individuals having higher tolerance scores [54]. Our work extends previous studies by confirming tolerance effects on power output while controlling statistically for self-reported physical activity level (as evaluated using the IPAQ). Indeed, in the present study, we characterised the participants by the total quantity of physical activity performed during a typical week across three categories of exercise intensities, which included for example the time spent per week doing house work, gardening, and walking to work in addition to the information classically noted on the number of hours per week spent doing leisure sports. By doing so, we revealed that it may be the individuals' tolerance level (and not self-reported physical activity level) that predicts the choice in exercise intensity.

Contrary to the Low Tolerant individuals, High Tolerant individuals demonstrated the overall tendency to increase exercise intensity progressively during the course of a session. Setting the exercise intensity to "moderately difficult" but on the low end of a continuum, these participants may have detected a mismatch, i.e. a level of discomfort smaller than that expected when considering their predicted tolerance threshold (see Fig 6). Hence, intensity of practice was augmented progressively to reduce the discrepancy between true and predicted inner states of discomfort. This process may have led the High Tolerant participants in the present study to reach the high end of the moderate continuum by the end of the session, while maintaining good levels of positive affective states. The Low Tolerant group on the other hand may have found a direct match between predicted and true inner states of discomfort leading them to maintain a constant intensity of practice throughout the cycling sessions, remaining at the low end of the moderate intensity continuum.

b) Music is a booster in High Tolerant individuals

Our results confirmed the positive impact of music in the High Tolerant group by showing that individuals cycling in music produced greater power output and experienced more positive affective states than those practicing in silence. Furthermore, the dynamic increase in power output across the duration of the session was significantly greater for the group cycling in music than the one cycling in silence. Compared to the few studies in the literature that used a production-mode protocol, our findings are consistent [55]. For example, Elliott et al. [56,57] had participants cycle for 12 minutes on an ergo-cyclometer at an intensity perceived as « somewhat difficult » (RPE 13) in silence, while listening to neutral or to motivational music. Authors observed that the motivational music had the effect to increase the pedalling distance and the positive affective states. In the present case**,** High Tolerant individuals in the music condition may have used the auditory energizing music to entrain each pedal push to the beat of the music, facilitating the production of the motor task. Furthermore, the importance set on the actual (true) sensory feedback may also have been minimized, i.e. music inhibited the perception of inner states of discomfort that emerged from the increase in exercise intensity. As a consequence, for similar levels of exercise intensity, the perceived level of discomfort with music was weaker than that experienced when cycling in silence. Exercise intensity could be increased until a match between predicted and true sensory feedback was attained leading High Tolerant individuals to exercise at greater intensities when cycling in music than in silence, at a similar perceived exertion scale of RPE13.

c) Little effects of music for Low Tolerant individuals

Contrasting results were found in the Low Tolerance group. Here, whatever the self-reported physical activity level, participants cycling with music produced similar levels of power output and reported similar degrees of positive affective states than those cycling in silence. However, as in the High Tolerant groups, mean heart rate frequency was significantly greater in the group cycling in music than the group cycling in silence. Hence, for the Low Tolerant participants specifically, music induced an increase in heart rate without providing the ability to produce greater power output. In the literature, greater heart rate has been associated to higher perceived exertion [36,58,59]. Hence, the contrasting effects of music on heart rate and power output may be an indicator of the higher difficulties experienced by the Low Tolerant individuals to perform a physical exercise in music rather than in silence. Four contrasting hypotheses may be considered to understand the origin of such difficulty. First, music has an entrainment power that has been well documented in the past ten years [46]. The groove contained within the musical playlists may have increased body rhythmicity [47] and modulate body posture [48]. The entrainment effect of music would have then led Low Tolerant individuals to cycle at a pace too high compared to their predicted acceptable level of discomfort. Another possibility is that participants used cognitive strategies to resist the entrainment effect of the music. Increasing the cognitive load would make the cycling in music task more cognitively challenging than cycling in silence. Individuals would in addition feel a discordance effect, which may increase furthermore the expressed levels of discomfort. Third, music is known to have a distracting effect. By narrowing attention, music can divert the mind from sensations of fatigue and inner senses of discomfort [4,5,60]. In the present case, the dissociation phenomena of music may have turned attention away from detecting the emergence of sensorial negative feelings that cue the forthcoming loss of homeostasis. Finally, set in a high state of arousal, Low Tolerant individuals may have simply been perturbed by the activating effects of music [61]. Further studies are now required to parcel apart the relative contributions of these different possibilities, taking into account tolerance levels to physical effort but also controlling for other factors like the cognitive abilities associated to the planning of sequential motor activities.

d) Pleasure is an affect that varies over time

Following the writings of Csikszentmihalyi [62], pleasure is an experience that is "homeostatic", i.e., it incorporates affective states that do not produce psychological growth but satiates biological needs. Pleasurable experiences make us feel good at a given moment. Previous studies have based their assumptions on the fact that changes in affective states, which take place between the start and the end of a session – follow a linear course [19]. However, by assessing the affective states periodically (every 5'), we show here that affective states evolve none linearly through the course of an exercise session. Contrasting affective dynamics may even characterise High and Low Tolerant individuals (see Fig 4) but additional observations are required. More specifically, future studies need to sample affective states throughout the practice sessions at an individual level and with adequate frequency, to gain a better understanding of the possible causal relationship between heart rate frequency, exercise intensity and the observed variations in affective states. As the pleasure experienced in the last 5 minutes of a session is predictive of positive emotional memories [63], the assessment of the changes in affective states during moderate physical activity may be a key variable to target when seeking to convey compliance to regular practice in individuals prone to low thresholds of physical effort and muscle pain.

VI. Concluding remarks

High and Low Tolerant individuals participated in a production-mode protocol in which they were asked to cycle at a moderate intensity felt as « somewhat difficult » (RPE13 on the Borg scale). We show that music is a booster for High Tolerant individuals: the musical environment gave them the ability to produce greater power output while experiencing even more pleasure than when cycling in silence. Low Tolerant individuals experienced with music an increase in heart rate frequency without gain in power output or pleasure, suggesting distress and discomfort when practicing in an energizing environment. Interestingly, music brought greater pleasure to the High than to the Low Tolerant participants even if both groups reported similar levels of enjoyment (PACES at the end of the session). Hence, pleasure and enjoyment may be two different concepts [64] that should be dissociated when seeking to develop pleasurable sports. Additional studies are needed to reveal which of pleasure or enjoyment is the key to promote durable motivation to an active life style in individuals with high and low tolerance to exercise intensity.

Acknowledgements

Research was supported by grants from the French Research Agency ANR-2009-CORD-014-INTERACT and ANR-11-EQPX-0023, and by funding to YD from the region Nord-Pas-de-Calais and Decathlon, S.A. (ARCIR2013). The authors report no competing interests. Special thanks to G. Dupont and B. Delaval for their help in data analysis (LOSC, France) and the general clinicians of the University of Lille.

References

1. Ekkekakis P, Hall EE, Petruzzello SJ. Some like it vigorous: measuring individual differences in the preference for and tolerance of exercise intensity. J Sport Exerc Psychol. 2005.

2. Annesi JJ. Effects of music, television, and a combination entertainment system on distraction, exercise adherence, and physical output in adults. Canadian Journal of Behavioural Science/Revue canadienne des sciences du comportement. 2001;33(3):193–202.

3. Pretty J, Peacock J, Sellens M, Griffin M. The mental and physical health outcomes of green exercise. Int J Environ Health Res. 2005 Oct;15(5):319–37.

4. Jones L, Karageorghis CI, Ekkekakis P. Can high-intensity exercise be more pleasant?: attentional dissociation using music and video. J Sport Exerc Psychol. 2014 Oct;36(5):528–41.

5. Privitera GJ, Antonelli DE, Szal AL. An Enjoyable Distraction During Exercise Augments the Positive Effects of Exercise on Mood. J Sports Sci Med. 2014;13(2):266–70.

6. Eurobarometer (2010). Sport and Physical Activity.

7. Dishman RK, Buckworth J. Increasing physical activity: a quantitative synthesis. Med Sci Sports Exerc. 1996 Jun;28(6):706–19.

8. American College of Sports Medicine, Thompson WR, Gordon NF, Pescatello LS. ACSM's guidelines for exercise testing and prescription. Philadelphia: Lippincott Williams & Wilkins; 2010.

9. Perri MG, Anton SD, Durning PE, Ketterson TU, Sydeman SJ, Berlant NE, et al. Adherence to exercise prescriptions: effects of prescribing moderate versus higher levels of intensity and frequency. Health Psychol. 2002;21(5):452–8.

10. Cox KL, Burke V, Gorely TJ, Beilin LJ, Puddey IB. Controlled comparison of retention and adherence in home- vs center-initiated exercise interventions in women ages 40-65 years: The S.W.E.A.T. Study (Sedentary Women Exercise Adherence Trial). Prev Med. 2003;36(1):17–29.

11. Williams DM, Dunsiger S, Ciccolo JT, Lewis BA, Albrecht AE, Marcus BH. Acute affective response to a moderate-intensity exercise stimulus predicts physical activity participation 6 and 12 months later. Psychology of Sport and Exercise. 2008;9(3):231–45.

12. Williams DM, Dunsiger S, Jennings EG, Marcus BH. Does affective valence during and immediately following a 10-min walk predict concurrent and future physical activity? Ann Behav Med. 2012;44(1):43–51.

13. Van Landuyt LM, Ekkekakis P, Hall EE, Petruzzello SJ. Throwing the mountains into the lake: On the perils of nomothetic conceptions of the exercise–affect relationship. Journal of Sport & Exercise Psychology. 2000;22(3):208–34.

14. Rose EA, Parfitt G. A quantitative analysis and qualitative explanation of the individual differences in affective responses to prescribed and self-selected exercise intensities. J Sport Exerc Psychol. 2007 Jun;29(3):281–309.

15. Rose EA, Parfitt G. Exercise experience influences affective and motivational outcomes of prescribed and self-selected intensity exercise. Scandinavian Journal of Medicine & Science in Sports. 2012;22(2):265–77.

16. Ekkekakis P, Thome J, Petruzzello SJ, Hall EE. The Preference for and Tolerance of the Intensity of Exercise Questionnaire: a psychometric evaluation among college women. J Sports Sci. 2008;26(5):499–510.

17. Monnier-Benoit P, Groslambert A, Rouillon J-D. Determination of the ventilatory threshold with affective valence and perceived exertion in trained cyclists: a preliminary study. J Strength Cond Res. 2009;23(6):1752–7.

18. Parfitt G, Eston R, Connolly D. Psychological affect at different ratings of perceived exertion in high- and low-active women: a study using a production protocol. Percept Mot Skills. 1996;82(3 Pt 1):1035–42.

19. Ekkekakis P, Acevedo EO. Affective responses to acute exercise: Toward a psychobiological dose-response model. In: Acevedo EO, Ekkekakis P (Ed.). Human Kinetics; Champaign. Psychobiology of physical activity (2006: 91–109).

20. Ahmaidi S, Masse-Biron J, Adam B, Choquet D, Freville M, Libert JP, et al. Effects of interval training at the ventilatory threshold on clinical and cardiorespiratory responses in elderly humans. Eur J Appl Physiol Occup Physiol. 1998;78(2):170–6.

21. Dwyer J, Bybee R. Heart rate indices of the anaerobic threshold. Med Sci Sports Exerc. 1983;15(1):72–6.

22. Demello JJ, Cureton KJ, Boineau RE, Singh MM. Ratings of perceived exertion at the lactate threshold in trained and untrained men and women. Med Sci Sports Exerc. 1987;19(4):354–62.

23. Gordon NF, Scott CB. Exercise intensity prescription in cardiovascular disease. Theoretical basis for anaerobic threshold determination. J Cardiopulm Rehabil. 1995;15(3):193–6.

24. Ekkekakis P, Lind E, Hall EE, Petruzzello SJ. Can self-reported tolerance of exercise intensity play a role in exercise testing? Med Sci Sports Exerc. 2007;39(7):1193–9.

25. Ekkekakis P. Pleasure and displeasure from the body: Perspectives from exercise. Cognition & Emotion. 2003;17(2):213–39.

26. Coquart JB, Garcin M, Parfitt G, Tourny-Chollet C, Eston RG. Prediction of maximal or peak oxygen uptake from ratings of perceived exertion. Sports Med. 2014;44(5):563–78.

27. Cabanac M. What is sensation? In R. Wong (Ed.), Biological perspectives on motivated activities. Norwood, NJ: Ablex; 1995: 399-418.

28. Damasio AR. Toward a neurobiology of emotion and feeling: Operational concepts and hypotheses. Neuroscientist. 1995, 1: 19-25.

29. Damasio AR. The feeling of what happens: Body and emotion in the making of consciousness. New York: Harcourt Brace. 1999.

30. Damasio AR. A neurobiology for consciousness. In T. Metzinger (Ed.), Neural correlates of consciousness: Empirical and conceptual questions. Cambridge, MA: MIT Press; 2000: 111-120.

31. Panksepp J. The periconscious substrates of consciousness: Affective states and the evolutionary origins of the self. Journal of Consciousness Studies. 1998b, 5: 566-582.

32. Schulze G. Motivation: Homeostatic mechanisms may instigate and shape adaptive behaviors through the generation of hedonic states. In R. Wong (Ed.), Biological perspectives on motivated activities. Norwood, NJ: Ablex; 1995: 265±288

33. Lind E, Joens-Matre RR, Ekkekakis P. What intensity of physical activity do previously sedentary middle-aged women select? Evidence of a coherent pattern from physiological, perceptual, and affective markers. Prev Med. 2005;40(4):407–19.

34. Rose EA, Parfitt G. Can the feeling scale be used to regulate exercise intensity? Med Sci Sports Exerc. 2008;40(10):1852–60.

35. Borg G. Borg’s perceived exertion and pain scales. Vol. viii. Champaign, IL, US: Human Kinetics; 1998. 104 p.

36. Eston RG, Williams JG. Reliability of ratings of perceived effort regulation of exercise intensity. Br J Sports Med. 1988;22(4):153–5.

37. Feriche B, Chicharro JL, Vaquero AF, Pérez M, Lucía A. The use of a fixed value of RPE during a ramp protocol. Comparison with the ventilatory threshold. J Sports Med Phys Fitness. 1998;38(1):35–8.

38. Stojiljković S, Nesić D, Mazić S, Popović D, Mitrović D, Mitić D. [Determination of ventilatory threshold based on subjective rating of perceived exertion]. Srp Arh Celok Lek. 2004;132(11-12):409–13.

39. Bubic A, von Cramon DY, Schubotz RI. Prediction, cognition and the brain. Front Hum Neurosci. 2010;4:25.

40. de Morree HM, Klein C, Marcora SM. Perception of effort reflects central motor command during movement execution. Psychophysiology. 2012;49:1242–53.

41. Eston R. Use of ratings of perceived exertion in sports. Int J Sports Physiol Perform. 2012;7(2):175–82.

42. Welch AS, Hulley A, Ferguson C, Beauchamp MR. Affective responses of inactive women to a maximal incremental exercise test: A test of the dual-mode model. Psychology of Sport and Exercise. 2007;8(4):401–23.

43. Mogil JS. The genetic mediation of individual differences in sensitivity to pain and its inhibition. Proc Natl Acad Sci U S A. 1999;96(14):7744–51.

44. Eysenck HJ. A note on ’Smoking, personality and reasons for smoking. Psychol Med. 1983;13(2):447–8.

45. Fulker DW, Eysenck SBG, Zuckerman M. A genetic and environmental analysis of sensation seeking. Journal of Research in Personality. 1980;14(2):261–81.

46. Leman M. Embodied Music Cognition and Mediation Technology, Cambridge, Mass.: MIT Press; 2007.

47. Simpson SD, Karageorghis CI. The effects of synchronous music on 400-m sprint performance. J Sports Sci. 2006;24(10):1095–102.

48. Wamain Y, Delevoye-Turrell Y. Move your body and I will tell you how you feel: Reading emotional states through body kinematics. Cognition and Emotion (submitted)

49. Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, et al. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc. 2003;35(8):1381–95.

50. Hardy CJ, Rejeski WJ. Not what, but how one feels: The measurement of affect during exercise. Journal of Sport & Exercise Psychology. 1989, 11: 304-317.

51. Delignières D, Pérez S. Le plaisir perçu dans la pratique des activités physiques et sportives : élaboration d’un outil d’évaluation. Revue S.T.A.P.S. 1998,45: 7-18.

52. Gobekli Tepe (documentary used). https://www.youtube.com/watch?v=NhhaRd-a8LU

53. Shaulov N, Lufi D. Music and light during indoor cycling. Perceptual and motor skills. 2009;108(2):597–607.

54. Hall EE, Petruzzello SJ, Ekkekakis P, Miller PC, Bixby WR. Role of self-reported individual differences in preference for and tolerance of exercise intensity in fitness testing performance. J Strength Cond Res. 2014;28(9):2443–51.

55. Karageorghis CI, Priest D-L. Music in the exercise domain: a review and synthesis (Part I). Int Rev Sport Exerc Psychol. 2012;5(1):44–66.

56. Elliott D, Carr S, Savage D. The effects of motivational music on work output and affective responses during sub-maximal cycling of a standardised perceived intensity. Journal of Sport Behavior. 2004, 27: 134-147.

57. Elliott D, Carr S, Orme D. The effect of motivational music on sub-maximal exercise. European Journal of Sport Science. 2005;5(2):97–106.

58. Ekblom B, Goldbarg AN. The influence of physical training and other factors on the subjective rating of perceived exertion. Acta Physiol Scand. 1971;83(3):399–406.

59. Robertson RJ, Falkel JE, Drash AL, Swank AM, Metz KF, Spungen SA, et al. Effect of blood pH on peripheral and central signals of perceived exertion. Med Sci Sports Exerc. 1986;18(1):114–22.

60. Bishop DT, Karageorghis CI, Loizou G. A grounded theory of young tennis players use of music to manipulate emotional state. J Sport Exerc Psychol. 2007;29(5):584–607.

61. Hilz M, Stadler P, Gryc T, Nath J, Habib-Romstoeck L, Stemper B, Buechner S, Wong S, Koehn J. Music induces different cardiac automic arousal effects in young and older persons. Autonomic Neuroscience : Basic and Clinical. 2014, 183: 83–93.

62. Csikszentmihalyi, M. *Flow: The Psychology Of Optimal Experience.* New York, Harper and Row. 1990, pp 40-49.

63. Redelmeier DA1, Katz J, Kahneman D. Memories of colonoscopy: a randomized trial. Pain. 2003. 104(1-2):187-94.

64. Decker ES, Ekkekakis P. More efficient, perhaps, but at what price? Pleasure and enjoyment responses to high-intensity interval exercise in low-active women with obesity. Psychology of Sport and Exercise. 2017.

Part 3

General Discussion

The flourishment is a state of positive mental health; to thrive, to prosper, and to fare well in endeavours free of mental illness, filed with emotional vitality and function positively in private and social realms (Michael et al., 2009). From a research standpoint, a multitude of studies have revealed that benefiting from a flourishing state leads individuals to achieve more goals than expected, to be more satisfied by their daily life activities and to experience greater physical and psychological health (for a review see Hefferon, 2013). Furthermore, the positive psychology suggests that the flourishment requires individuals to experience both positive and negative events. Experiencing positive events would enable individuals to create a «protective reservoir » upon which one can draw from during unpleasant and distressing times (Hefferon & Boniwell, 2011). On the other side, experiencing negative life moments would enable individuals to learn how to overcome his/her weaknesses through the enhancement of his/her strengths. Hence, a flourishing state will be reached only in those individuals who take risk to be in environment that require constant switch adaptation of motor behaviour to joyful and stressful life event. Consequently, flourishing is not an easy state to find and requires effort. As such, its reaching may differ between individuals.

Thanks to huge acute and chronic benefits of physical exercise, regularly exercising is considered as one way enabling individuals and communities to thrive and prosper through flourishment (Mutrie & Faulkner, 2004). However, while some individuals possess enough cognitive resources to handle the demands of the motor task and thus, discover pleasure during a session, some others are not able to do so (Backhouse et al., 2007; Van Landuyt et al., 2000). At a promotional level, this absence of positive experience may explain why 40 to 65 % of individuals initiating exercise programs are predicted to dropout within 3 to 6 months (Annesi, 2003). In fact, deciding to engage in a regular practice requires to negotiate with everyday costs and most of all *to support significant effort, discomfort and even exhaustion during the physical exercise* (Mullen, & Hall; Hall, & Fong, 2015). As such, incorporating the individuals' signature strengths into programme development activities may lead to greater exercise engagement and flourishment (Hefferon, Mutrie, 2012). More specifically, one needs to ***focus on the enhancement of strengths rather than on the strengthening of weaknesses*** to experience positively a task (Hefferon, 2013). When challenging their strengths, individuals may create a "protective reservoir" upon which they will be able to draw from when the physical exercise becomes more (too) difficult. On the other side, when challenging their weaknesses individuals may experience difficulties when facing to the requirement of adjusting continuously their motor behaviour while they do not possess enough resources to do so. Hence, building training programs focusing on the enhancement of strengths will lead one to benefit from an enhancement of one's motor control, mastering, enjoyment of body movement. Following these positive experiences should then increase the adherence to regular practice. Stocker (2012) conducted a study based on this theoretical idea of strengths-based physical activity programme. He reported that when individuals were given a personalized programme based on activities using their strengths instead of their weaknesses, participants benefited from an enhancement of their self-efficacy and their sense of achievement. Furthermore, through this individualized approach, all individuals enjoyed the session.

More recently, it was suggested that during the performance of a physical exercise cognitive resources are required to help individuals in the self-regulation of the cognitive challenges occurring during the planning and the execution of the motor task (Audiffren, 2016; Audiffren and André, 2015; Burzynska et al., 2017; Müller et al., 2017; Pesce, 2016). Large interindividual differences exist when considering the cognitive resources required to handle the demands of a motor task (Goodway & Branta, 2003; Goodway, Suminski, & Ruiz, 2003; Hamilton, Goodway, & Haubenstricker, 1999; Langendorfer & Roberton, 2002a, 2002b; Williams, Haywood, & VanSant, 1991). Large individuals' differences also exist when looking at basic abilities to handle difficulty or pain (Mogil, 1999). Indeed, some individuals will tolerate higher amounts of pain compared to others who will prefer to move at an intensity that will minimize physical discomfort and pain. Consequently, the general aim of this thesis work was to understand an individual's motor control strengths, especially executive strengths, may predict the way that person is able to tolerate the pain and discomfort occurring during the performance of a physical exercise in relation to self-regulation strategies.

I. The main findings

The first step of this thesis work was to conduct experimental research in order to obtain a cognitive definition of physical exercise.

a) Defining physical exercise throughout their cognitive load

To flourish through physical exercise, individuals are required to be able to handle the challenges occurring during the planning and the execution of the motor task. Study II aimed at confirming that physical exercise should be defined as a function of the complexity of the motor task and the cognitive resources needed to handle the challenges occurring during the task. A dual-task paradigm was developed to assess the amount of cognitive resources needed to perform an ecological whole body physical exercise. We revealed that the more physical exercise was challenging during planning and execution, the more individuals perceived their performance as cognitively demanding. In fact, the dancing condition was experienced as more cognitively demanding than did cycling and stepping conditions. Furthermore, through the use of a self-paced protocol, we confirmed that the way one perceives the difficulty of a physical exercise depends on the integration of both the physical (Eston et al., 2012) and the cognitive loads experienced during the motor performance (Abbiss et al., 2015). In fact, by combining the perception of the physical and cognitive loads experienced during the physical exercise, perceived effort was explained by 38 %. In regard to the results obtained in Study II, we can confirm that cognitive functions are required during physical exercise (Audiffren, & André). Furthermore, a physical practice should take into account both the physiological and cognitive demands of the motor task (Burzynska et al., 2017; Müller et al., 2017; Pesce, 2016).

The specificity of the experimental design presented in this thesis work, was the elaboration of a self-paced design during which the perception of effort was fixed. As such, the individuals had the possibility to increase or decrease the intensity of the motor output performed throughout time. Hence, the involvement of cognitive functions during the physical exercise sessions was most probably related to the necessity to self-regulate the motor output intensity in order to stand the “somewhat difficult” effort. Furthermore, results obtained in Studies II, III and IV suggest that the cognitive monitoring of behaviour during the course of a “somewhat difficult” physical exercise is not equal between Low and High Tolerant individuals.

b) Assessing one individual's Tolerance to effort to predict one's ability to handle the cognitive demands of physical exercise

The effort perceived during the performance of a motor task is defined as emerging from the comparison between a predicted and an actual sensory-motor information (Abbiss et al., 2015). More specifically, in order to strive, move efficiently and interact safely, individuals must anticipate the effort they will need to plan and execute adequately a motor task. Hence, during the performance of sequences of movements a comparison is made between the effort that participants predicted and the actual effort they are experiencing. In a case of a match, the perceived effort corresponds to the predicted one. Thus, individuals can run and pursue the course of their motor production. However, in the case of a mismatch, the actual perceived effort does not correspond to the predicted one. Hence, individuals will require to re-adjust their motor output until the actual effort perceived corresponds to the predicted one. The necessity to on-line monitor, re-plan and re-execute the movement will lead individuals to experience the motor performance as cognitively more demanding, i.e., more effortful than in a case of a perfect match.

In the present task, we took the standpoint that the effort discrepancy may be related to the concept of Tolerance (Ekkekakis, 2005). Thus, we systematically used the Tolerance scale in the studies to reveal possible contrasts between low and high tolerant individuals. In Study I, the statistical analyses conducted on the Tolerance subscale led to a good construct of the French-speaking version of the questionnaire. More specifically, when deleting the items 3 and 15 from the original questionnaire, the internal consistency of the Tolerance subscale was equal to 0.76. Moreover, the test-retest reliability of the Tolerance subscale was equal to 0.90 at 3-month and at 4-month delays. More importantly, the concept of Tolerance was valid whatever the “level of self-reported physical exercise” of individuals. In fact, the internal consistency of the Tolerance subscale ranged from 0.71 to 0.78 when performing the statistical analyses in inactive, active and athletic populations. These findings led us in the following studies of this thesis to test samples that were characteristic of the general population, with both inactive and active adults.

Based on the French validation of the Tolerance to effort concept (Study I), the results obtained in Study III revealed that Low Tolerant individuals, i.e., individuals who are less able to continue exercising at an imposed level of intensity when the activity becomes uncomfortable or unpleasant (Ekkekakis, Hall & Petruzzello, 2005), possess weaker executive functions than High Tolerant individuals. More specifically, their working memory span was lower than that measured in the High Tolerant individuals. In addition, the results revealed that compared to High Tolerant individuals, Low Tolerant individuals possessed weaker abilities to inhibit their motor behaviour, especially when following an error. In regard to these results, it is possible that Low Tolerant individuals are characterised by weaker abilities to self-regulate motor output as a function of the effort they are perceiving. Furthermore, the cognitive load generated by the constant adjustment of motor output may be the source of the greater cognitive load experienced during physical exercise than High Tolerant individuals.

The findings presented throughout Studies III and IV are thus coherent: (1) High Tolerant individuals self-regulate their motor performance differently than Low Tolerant individuals; (2) while High Tolerant are characterised by an overall spontaneously increase in the intensity of motor output throughout a session, Low Tolerant remain at a constant exercise intensity; (3) although Low Tolerant individuals do not increase the intensity of physical exercise throughout time, heart rate frequency is similar to that observed in the High Tolerant participants. Hence, Low Tolerant may have weaker abilities to update relevant information and to inhibit non-relevant sensory-motor related cues during motor performance, which offers fewer possibilities for efficient re-adjustment most of motor output in the context of physical exercise.

Similar interpretations are supported by the results presented in Study II. Indeed, we revealed that when asking individuals to perform a cognitive task in addition to the physical exercise, Low Tolerant individuals perceived the performance as more exhausting than did High Tolerant individuals. Furthermore, when the physical exercise was the most complex in terms of motor planning, execution and self-regulation (i.e., dancing), the counting performances of Low Tolerant individuals were less efficient than that observed in all other conditions. The results are all the more powerful that the statistical analyses were conducted by controlling for the individuals' self-reported weekly physical exercise (i.e., fitness level).

It is the case that the difficulties objectively encountered by Low Tolerant individuals during the course of "somewhat difficult" physical exercise is supported through their global subjective affective experience of the session. Hence, in the next section, we will consider the importance of affective states for better understanding of the contrasting self-regulation strategies observed in High and Low Tolerant individuals for greater flourishment through physical exercise.

c) Tolerance and affective state for pleasurable physical exercise

Affective states provide the primary means by which information about critical disruptions of homeostasis enter consciousness (Cabanac, 1979; Panksepp, 1998 – as cited by Ekkekakis, 2013). It is the case that, affective states emerge from the discrepancy that may occur when integrating the predicted and the actual sensorial information when moving (Carver, & Scheier, 1998; Frijda, 1988; Frijda, 1986 - as cited by Carver, Johnson, Joorman, & Scheier, 2015). Hence, the leading hypothesis in this thesis was that differences in sensorial affect should be observed in Low and High Tolerant individuals.

Physical exercise was reported to be more effortful (Study II), more cognitively demanding (Study II) and overall less pleasant (Study II and IV) in Low Tolerant individuals than in High Tolerant individuals. Hence, we can suggest that due to their weaker executive functions, Low Tolerant individuals may experience more difficulties to update relevant information, and to inhibit non-relevant sensory-motor cues while exercising. Thus, due to their weaker self-regulation strategies, they may experience higher negative states because of perceived higher threat to their homeostasis while performing a physical exercise. This hypothesis is supported by the results obtained in Studies II and IV. In Study IV, results suggested that when asking both Low and High Tolerant individuals to perform a cycling task, similar affective states are observed. However, while the music allows the High Tolerant individuals to perceive the cycling exercise as more pleasant than did High Tolerant individuals who performed in silence, the affective states of Low Tolerant individuals performing in music or in silence did not differ. Interestingly, although these Low Tolerant individuals did not increase the intensity of the physical exercise, their heart rate frequency increased. Hence, we may propose that Low Tolerant individuals are able as much High Tolerant individuals to cognitively handle a physical exercise like cycling in silence. However, asking them to perform a dual-task like counting and listening to music while exercise requires cognitive resources that they do not have; leading them to experience more negatively the session (Study II) or to express their difficulties throughout an increase in heart rate frequency (Studies III and IV) compared to High Tolerant individuals. What may the effect of these sensorial reactions to exercise for an individual's engagement to regular practice?

d) Tolerance and affective states to engage in a regular practice

The affective states experienced during a session is defined as contributing to the formation of either a positive or negative memory trace for exercise, which in turn may influence consciously or subconsciously subsequent decisions to engage in, adhere to or drop out from exercise (Ekkekakis et al., 2011) . In Study II we confirmed that the desire of participants to re-exercise was a function of the affective states they experienced during the session (Jekauc, 2015; Wienke & Jekauc, 2016; Zenko, Ekkekakis, & Ariely, 2016). However, results revealed also that the affective states experienced during motor performance was a function of an individual's Tolerance level. Hence, in daily life, we may hypothesise that Low Tolerant individuals may experience weaker positive affective states during the course of a physical exercise which would lead them to be more sensitive to drop out of an exercise program than may do High Tolerant individuals. In a study recently conducted in collaboration with Decathlon Sportslab (Villeneuve d'Ascq, France), we revealed that for a same quantity of self-reported weekly physical exercise, Low Tolerant individuals were indeed characterised by weaker abilities to explain the reason why they engage in a regular practice than did High Tolerant individuals (Carlier, Boidin, Delplanque, & Delevoye-Turrell, in preparation). Furthermore, when they were able to describe the motive of drop out, participants showed lower levels of intrinsic motivation than did High Tolerant individuals. In regard to these results, future research is required to focus on the understanding of the condition that may lead Low Tolerant individuals to be more intrinsically motivated to lead them to flourish through regular practice without the need of extrinsic motivators. For example, in a recent study (Carlier, Calais, & Delevoye-Turrell, in preparation) we reported that Low Tolerant individuals can experience a strenuous bout of exercise but only if the session lasted for 3 minutes. These findings open the way to new research future, and suggest assessing if the most flourishing physical exercise for Low Tolerant individuals may be those which do not require long self-regulation session (e.g., 30 minutes). In fact, Low Tolerant individuals may be more enjoyed in short bout of exercises like those proposed during intermittent session.

e) Conclusion about the findings

The results obtained in this thesis work allow to suggest that to encourage most people to flourish through regular physical exercise several things must be considered. First, physical exercise must be defined from the cognitive resources they require. Second, individuals' cognitive efficiency and Tolerance to effort must be considered as they predict the way one is able to handle the demands of the physical exercise. Finally, the affective states reflect the physical and cognitive difficulties that individuals encounter during the course of a physical exercise and may be critical variable to use as intensity controller. Nevertheless, at least critical questions remain.

II. Remaining questions

First, individual’s Tolerance was defined as depending on both physical and cognitive abilities. But how to quantify the dependency and independency between these two aspects? Second, individuals are constantly faced to environmental changes leading them to sometimes being more exhausted on some days than on others. Thus, could we consider that Tolerance may fluctuate and may be constituted by both a trait and a state feature? Finally, and most importantly in this thesis work, how could we relate Tolerance to effort to the ability to reach a flourishing state through physical exercise?

a) Defining the physiological and the psychological indexes of Tolerance to effort during the performance of a physical exercise

Differences between Low and High tolerant individuals have been reported from a physiological point of view. In these studies, tolerance of exercise intensity is revealed to be predictive of oxygen consumption during exercise (Schneider & Graham, 2009), of the motor production (Hall et al., 2014) and also to be predictive of the ability to continue a physical exercise even if the physiological and physical resources are sold out (Ekkekakis et al., 2005). Interestingly, when considering the dual mode theory, few experimental studies have tried to analyse how the physiological and cognitive abilities of individuals interact during physical activity. More specifically, it is unknown to date whether the differences observed between low and high tolerant individuals on oxygen consumption, motor production and individuals’ perseverance are only a function of physiological abilities or emanating from the integration of both physical and cognitive resources. Hence, future research may be conducted to study the causal links between (1) the efficiency of an individual’s cognitive functioning and (2) his/her physiological regulation abilities during the performance of a physical exercise. This transdisciplinary project will enable a better understanding of how this interaction may predict the affective states (pleasure, displeasure) experienced during physical exercise, as stated in the dual mode theory of Ekkekakis et al. (2003). For instance, we may study, by controlling for individuals objectively reported weekly physical exercise (i.e., measured through Actigraph), whether Low and High Tolerant individuals are characterised by different physiological functioning, namely the Ventilatory Threshold occurrence (VT). Second, we may study how individuals' interaction between physiological and cognitive resources may differ as a function of the individuals' tolerance level and the intensity of the physical exercise performed (i.e., below the VT, around the VT, above the VT). However, such studies may require asking individuals to come several times. Hence, measuring possible variation in one's Tolerance level may be useful, and necessary.

b) Defining Tolerance to effort into a Trait and a State components to enhance individuals training programs

Tolerance Trait may be defined as emerging from the interaction between educational differences, physiological abilities and cognitive and physical resources. More specifically, during the course of development, one's genetics will enable one to develop physiological pain and tolerance to discomfort. Hence, thanks to true experience and learning to interact with the world, one will develop stable tolerance abilities and coping strategies. Then, throughout their maturation, children and adolescents will develop their cognitive abilities. Thus, from an embodiment framework, their cognitive efficiency will depend on one's physiological and physical competences. The interaction between the three (i.e. educational environment, physiological resources and cognitive and physical resources) will then enable the emergence of one's Tolerance level. (Fig. 1-*left*)

On the other side, individuals are constantly faced to environmental changes leading them to sometimes being more exhausted than other days. Hence, individual's Tolerance State may exist from the interaction between daily emotional states, cognitive and physical abilities and physiological resources that are available at a specific moment (Fig. 1-*right*). To confirm such a theoretical idea, studies need to be conducted looking at the stability of the Tolerance scale in a longitudinal study in a large cohort of healthy individuals.

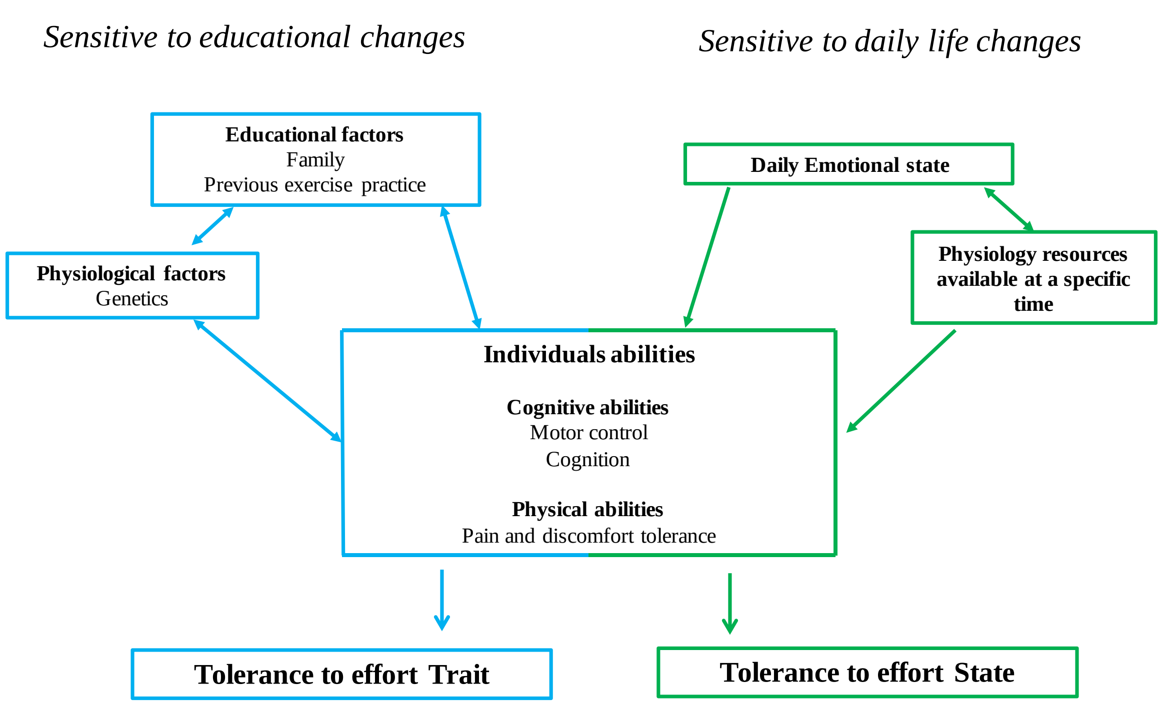


Figure 4 : Schematic representation of individuals' Tolerance Trait and Tolerance State.

c) The Integrative model of physical exercise dynamic for adherence and flourishment

When looking at the benefits of physical exercise on cognitive functioning, we observe that (1) all individuals can cognitively benefit from physical exercise with younger and older individuals being the most sensitive, (2) the cognitive functions devoted to the self-regulation of motor behaviour (i.e., the executive functions) are the most sensitive to an enhancement, and (3) contrary to physiological and physical competences, the cognitive performance gains do not differ as a function of the percentage of improvement in aerobic fitness (Etnier, 2008; Etnier, Powell, Landers, & Sibley, 2006). Hence, in regard to this pattern of results, it was suggested that the cognitively benefits depends on both moderators and mediators (Spiriduso, Poon, Chodzko-Zajko, 2008).

A moderator is defined as a third variable which partitions a focal independent variable into groups that establish its domains of maximal effectiveness in regard to a given dependent variable (Baron, & Kenny, 1986 – as cited by Etnier, 2009). A moderator can be categorical or continuous in nature, and affects the direction of the strength of the relationship between the independent and the dependent variables. In the field of sport psychology, a possible moderator influencing the relationship between the performance of a physical exercise and the cognitive benefits obtained may be the gender because men and women beneficiate differently from practice (Etnier, 2008). A mediator variable is defined as representing broader hypothetical constructs that influence the dependent variable of interest. In the field of sport psychology, a possible mediator influencing the cognitive benefits emerging from the performance of a physical exercise could be the quality of sleep. More specifically, the more individuals recover from effort performed during previous days, the more they are able to cognitively handle the task and thus, the more they can overall benefit from practice. Hence, the cognitive benefits observed after a single bout of physical exercise may emerge from both direct and indirect pathways (Spiriduso, Poon, Chodzko-Zajko, 2008).

Recently, the beneficial effect of exercising on cognitive functions was revealed as depending on individuals baseline abilities (Drollette et al., 2014; Godde and Voelcker-Rehage, 2017). More specifically, in adults, results revealed that when assessing the brain activation during motor imagery, the individuals with lower baseline motor performances were those who revealed the greatest improvements (Godde and Voelcker-Rehage, 2017). The notion that individuals baseline motor control abilities could explain, to some extent, the heterogeneity of the results was already supposed in adults (Pesce, 2010) and revealed in children (Drollette et al., 2014).

Throughout this thesis work we revealed that Low Tolerant individuals are characterised by weaker executive functions, i.e., the most elaborated cognitive functions devoted to motor control; leading them to self-regulate the intensity of their physical exercise with more difficulties than High Tolerant individuals. Hence, in regard to the aforementioned studies, we can hypothesise that because of their weaker executive functions, Low Tolerant individuals may greater benefit from physical exercise than High Tolerant individuals. However, since physical exercise can be defined from their motor complexity, the way Low Tolerant individuals may cognitively benefit from a practice may also depend on their abilities to handle the challenges occurring during the task (Fig. 2). Hence, the importance of designing, in future work, physical sessions adapted to Low Tolerant individuals' cognitive abilities, may be the best opportunities to offer Low

Tolerant individuals to discover flourishment through pleasurable physical exercise (Fig 2.)

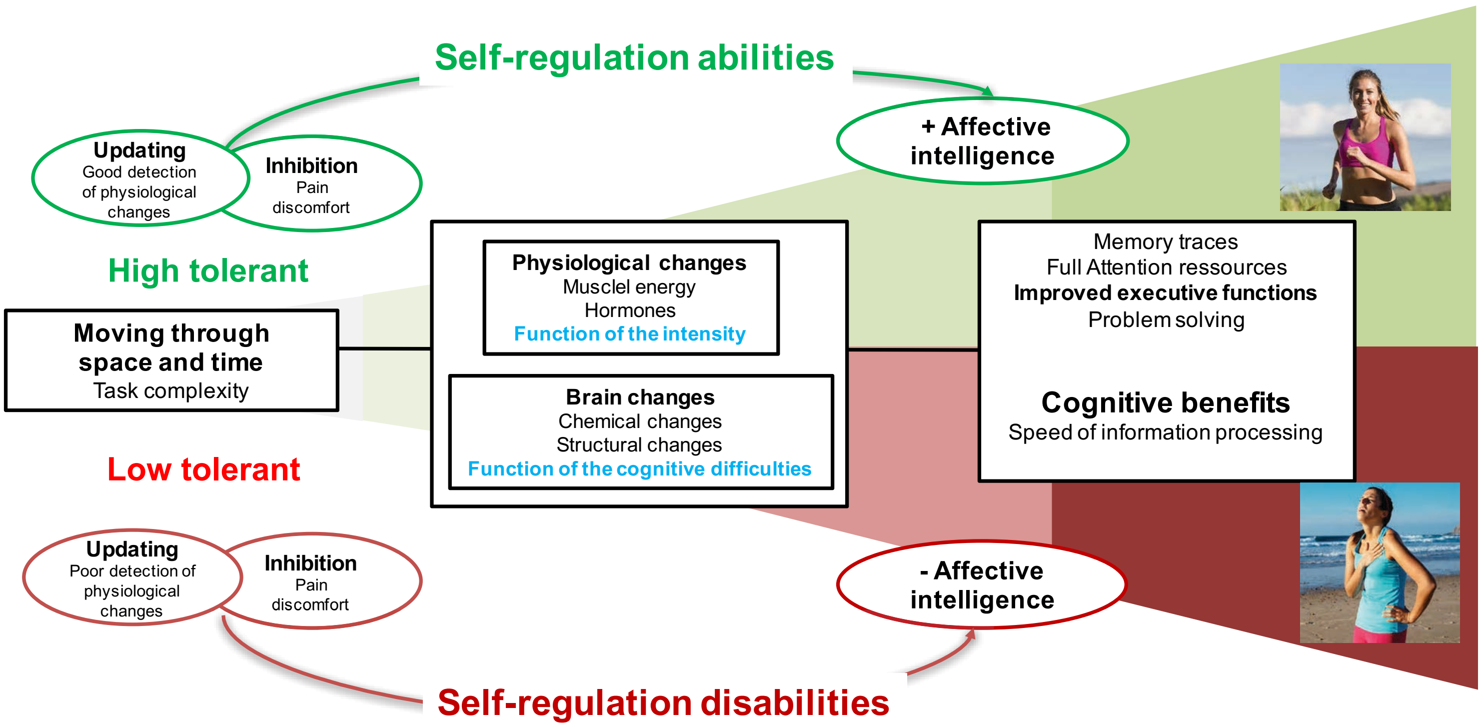


Figure 2: Schematic representation of the role of mediators and moderators in exercise effects on individuals' cognition and affective states. The more individuals are able to handle the challenges and the changes occurring their practice will lead them to experience positively the session and thus the possibility to flourish through regular physical exercise (green line). However, the less individuals are able to handle the challenges and the changes occurring their practice will lead them to experience negatively the session because of a high threat of their homeostasis; leading them to not be able to flourish through regular physical exercise (red line)(Adapted from Etnier, 2008)

III. Final conclusions

Physical and physiological abilities of an individual was for a long time the only features that were controlled and adapted for reducing the barriers for compliance to a physically active lifestyle. However, in regard to the results presented in this document, we have described experimental findings in line with the cognitive load theory of physical exercise. Our results highlight the importance of considering executive abilities for motor planning and adjustment during the practice of physical exercise, as cognitive capacities predict to a certain extent the affective consequences of physical exercise. Hence, to bring the most individuals to regular practice, it seems important in light of the present work to bear in mind two key points. The cognitive efficiency of patients and their tolerance to effort need to be considered when prescribing exercise programs as these elements predict (1) the cognitive benefits of exercise and especially, (2) the affective tag of the exercise session that predicts the future adherence to exercise practice.

IV. 5 rules towards flourishment through physical exercise

1. Focus on your strengths rather than your weaknesses.
2. Exercise as a function of your inner affective sensations states rather than performance measures.
3. Listen to your body with curiosity.
4. Acknowledge your pains and your limits of today; they may be different tomorrow.
5. Accept to be different as flourishment may emerge from a variety of sources such as enjoyment, mastery, friendship, wellbeing and even why not competition.

MAURAINE CARLIER

Name : Mauraine Carlier
*Nationality :*French
Work Address :
Laboratoire SCALab (CNRS, UMR 9193)
Université de Lille, Sciences Humaines et Sociales
Domaine universitaire du Pont de Bois
BP 60 149, 59653 Villeneuve d'Ascq Cedex
Private Address :
Appt, 11, 8 quai des chevillards
59800 Lille, France
Email Address : mauraine.carlier@orange.fr

EDUCATIONAL QUALIFICATIONS

- **2013-2017:** PhD student supervised by Pr. Yvonne Delevoye-Turrell, University of Lille Sciences Humaines et Sociales.
  Anticipated graduation: 27/11/2017

- **2013:** Licensed as practicing psychologist
- **2012/2013:** European Master 2 degree « Psychology of neurocognitive and affective science processes » specialization, University of Lille, Sciences Humaines et Sociales (Lille, France) and University of Minho (Braga, Portugal) -- First class distinction
- **2011/2012:** Psychology Master 1 degree, University of Lille, Sciences Humaines et Sociales
- **2008/2011:** Psychology Bachelor's degree, University of Lille, Sciences Humaines et Sociales
- **2007/2008:** High School diploma

GRANTS

- **February 2017:** *"Fulbright grant"* (selected to defend the research project; not funded)
- **2013/2016:** "*Research grant*" by the French Government (**funded** - 20100€/year),
- **2016, October:** Challenge Doc third prize (collaboration with Auchan Retail compagny)
- **2016, February:** Application for the "Programme Chercheurs-Citoyens" grant (not funded)
- **2014, June:** Oral communication third prize (5th International Congress of Sport Psychology. Sport Psychology for Performance and health accross the lifespan, 2014).
- **2012/2013:** "*International mobility grant*" by the French Government (**funded** -1600€).

PROFESSIONNAL EXPERIENCES

- **2016/2017:** Attaché d'Enseignement et de Recherche (full time teaching)
- **2013/2016:** Contrat doctoral (Teaching and Development of the laboratory research)
- **2016/-**: Preventing and predicting "runners" physical injuries by assessing their psychological and cognitive functioning in collaboration with the start-up "PremedIT"
- **2014/-**: Member of the working group "Activités Physiques Adaptées" du Réseau TC/AVC Nord 59/62
- **2015/2016:** Organization committee member of the "Motor Behavior and Emotion" international congress (November 21-23, 2016, Lille, France).
- **2016, October:** Challenge Doc (for the development of an innovative project for the Auchan Retail company - Lille, France).
- **2014/2015:** Secretary of the association « Espace Doctorants » at the University of Lille.
- **2013/2014 :** Member of the clinical working group directed by Marc Rousseau (Chief of the rehabilitation center « Swynghedaw », Lille, France).
- **2012/2013 :**
    - Organization committee member of the Symposium Vision, Action and Concepts.
    - Research work experience at NeuroPsychoPhysiology laboratory supervised by Dr. Ana Pinheiro
    - Clinical work experience at "EHPAD Feron Vrau" (Lille, France) with patients suffering from neuro-degenerative diseases supervised by Faouzia Gourari (psychologist).
    - Clinical work experience at "Centre de rééducation et de rééadaptation fonctionnelle l'Espoir" (Hellemmes, France) with patients suffering from stroke supervised by Yves Martin (psychologist).
    - Clinical work experience with the association "Saisic-Frontiers" (Lille, France) with patients suffering from mental diseases
- **2011/2012:** Clinical work experience at "Centre de rééducation Hopale" (Arras, France) with patients suffering from stroke supervised by Raphaël Levasseur (psychologist).
- **2010/2011:** Clinical work experience at "Hôpital maritime de Zuydcoote" (Zuydcoote, France) with patients suffering from neuro-degenerative diseases supervised by Faouzia Gourari (psychologist).
- **2011:** Research work experience at URECA laboratory supervised by Pr. Yvonne Delevoye-Turrell.

RESEARCH WORKS

- **2016/-**: **Regional collaboration with the start-up "PremedIT" (Lille, France):** Preventing and predicting "runners" physical injuries by assessing their psychological and cognitive functioning.

- **2016/-**: **Clinical collaboration (Hellemmes, France):** with the re-education center “Centre de rééducation et de réadaptation fonctionnelle l’Espoir”.
- **2016/2017: International collaboration:** with Pr. Panteleimon Ekkekakis (Iowa University State, USA), Dr. Laurence Desjardins-Crépeau and Pr. Louis Bherer (Cognitive Health and Aging Research Lab, University of Montréal, Montréal, Québec), and Pr. Yvonne Delevoye-Turrell (University of Lille, France) on the French validation of the Preference to and Tolerance of Exercise Intensity Questionnaire (PRETIE-Q).
- **2013/2017: PhD thesis: “**Quantifying individuals cognitive functioning required for enjoying and regularly practicing a physical activity” under the supervision of Pr. Yvonne Delevoye-Turrell.
- **2012/2013: Master 2 research: “**Cognitive exercise through body movement: Using a fun and short neuropsychological tool to adapt physical activity and enhance pleasure in individuals suffering from mental illnesses” under the supervision of Pr. Yvonne Delevoye-Turrell.
- **2011/2012: Master 1 research: “**The perception of peripersonal space in right and left brain damage hemiplegic patients” under the supervision of Pr. Yann Coello.

PUBLICATIONS

- ### Articles in indexed review

Carlier, M., Delevoye-Turrell, Y. Ekkekakis, P., Desjardins-Crépeau, L., Bherer, L. The Psychometric Properties of The Preference for and Tolerance of Exercise Intensity Questionnaire (PRETIE-Q) in French-Speaking individuals (*in preparation*).

Carlier, M., Delevoye-Turrell, Y. The Cognitive Load of Physical Exercise: Effects of Task Complexity and Individuals’ Level of Tolerance. (*in preparation*).

Carlier, M., Delevoye-Turrell, Y. A Neuropsychological Approach to the Tolerance of Exercise Intensity Concept and its Application in the Self-Regulation of Moderate Physical Exercise. (*in preparation*).

Carlier, M., Calais, J., Delevoye-Turrell, Y. Does the Tolerance of exercise intensity is related to motor imagery? (*in preparation*).

Carlier, M., Delevoye-Turrell, Y. (2017). Tolerance to exercice intensity modulates pleasure when exercising in music: the upsides of acoustic energy for high tolerant individuals. *Plos One.*

Carlier, M., Mainguet, B., & Delevoye-Turrell, Y. (2016). Cognitive exercise through body movement: Using a fun and short neuropsychological tool to adapt physical activity and enhance pleasure in individuals suffering from mental illnesses. *Psychologie Française, 61*(4), 349–359.

Bartolo, A., **Carlier, M.,** Hassaini, S., Martin, Y., & Coello, Y. (2014). The perception of peripersonal space in right and left brain damage hemiplegic patients. *Frontiers in Human Neurosciences.*

- ## Abstracts in indexed review

Carlier, M., Delevoye-Turrell, Y., Dione, M. (2014). Cognitive Benefit of Physical Activity Increased when Producing Rhythmic Action. *Procedia - Social and Behavioral Sciences*, 126, 235–236.

COMMUNICATIONS

- ## Invited speaker

Carlier, M., Delevoye-Turrell, Y. (2016, October). Physical activity, mental health and rehabilitation using new technologies: how to improve pleasure during a moderate physical activity. AlterEgo worshop (Montpellier, France).

- ## Oral presentations in scientific meetings

Carlier, M., Delevoye-Turrell, Y.(2017, August). L'évaluation des capacités d'inhibition prédétermine la tolérance à l'effort physique. 58ème Congrés de la Société Française de Psychologie (SFP, Nice, France).

Carlier, M., Delevoye-Turrell, Y. (2016, November). What is the feel-good experience in low and high tolerant individuals? Motor Behavior and Emotion international congress (Lille, France)

Carlier, M., Delevoye-Turrell, Y. (2015, December). L'évaluation des capacités d'inhibition prédétermine la tolérance à l'effort physique. 10ème Journée Scientifique des Jeunes Chercheurs (Lille, France).

Carlier, M., Houriez, P., Pottrain, C., Delevoye-Turrell, Y. (2014, July). Neuropsychology battery, Physical Activity and Benefits quantified. 28th International Congress of Applied Psychology (ICAP, Paris, France).

Carlier, M., Delevoye-Turrell, Y. (2014, May). Quantifying the benefits of physical activity on executive functioning as a function of the complexity of motor planning. The SFPS' 5th International Congress of Sport Psychology. Sport Psychology for Performance and health accross the lifespan (Nice, France).

Carlier, M., Delevoye-Turell, Y. (2013, September). Amélioration des fonctions exécutives, de la cognition haute et des processus psychologiques par une pratique physique. 54ème Congrés de la Société Française de Psychologie (SFP, Lyon, France).

- **Posters presentations in scientific meetings**

Carlier, M., Delevoye-Turrell, Y. (2016, February). Assessment of inhibition predetermines the tolerance to physical effort. $44^{ème}$ Meeting annuel de Neuropsychologie (INS, Boston, USA).

Carlier, M., Delevoye-Turrell, Y. (2015, July). Our tolerance to effort predetermines the pleasure and the cognitive benefits of physical practice. 14^{th} European Congress of Sport Psychology (FEPSAC, Bern, Suisse).

Houriez, P., Martin, Y., **Carlier, M.,** Delevoye-Turrell, Y. (2014, June). Activité physique et récupération cognitive suite à un accident vasculaire cérébral. Journée d'étude «Bien-être et APS » (Paris, France).

Carlier, M., Dupont, G., Delevoye-Turrell, Y. (2014, June). Quantifying the benefits of physical activity on executive functioning and well-being as a function of the complexity of motor planning. Journée d'étude «Bien-être et APS» (Paris, France).

Carlier, M., Delevoye-Turell, Y. (2014, February). Batterie de tests neuropsychologiques, Activités Physiques et Psychiatrie. Journées internationales de neuropsychologie des lobes frontaux et des fonctions exécutives (Angers, France).

Delevoye-Turrell, Y., **Carlier, M.,** Carlton, O., Mainguet, B. (2013, April). Using Artificial Neural Networks to predict the probability of treatment observance during adapted physical activity. 14th International Congress on Schizophrenia Research (USA).

Carlier, M., Delevoye-Turrell, Y. (2013, May). Study of impact of Adapted Physical Activities (APA) on Cognitive Functions and elaboration of a neuropsychological battery. IV Seminario de Investifaçao em Psicologia da Universidade do Minho (Braga, Portugal).

Carlier, M., Poulain, A., Bachelet, C., Labire, J., Martin, Y., Hassaini, S., Levasseur, R., Merle, F., Coello, Y., Bartolo, A. (2012, June). Perception de l'espace d'action et imagerie motrice chez des patients hémiplégiques. Symposium International de Neuropsychologie : Réhabilitation Cognitive et prise en charge Chirurgicale (Lille, France).

TEACHING

- **2016-2017**
  - **Psychology**
    - Cognitive Psychology (2^{nd} year degree, 18h)

            - Neurosciences (3rd year degree, 18h)
            - Neurocognition (3rd year degree, 10h)
            - Neurocognition and affective sciences (3rd year degree, 15h)
            - Literature research (3rd year degree, 42h)
            - Research design initiation (1st year degree, 18h)
            - Experimental methodology (1st year degree, 6h)
            - Statistics (1st year degree, 12h)
        - **MIASHS (Mathématiques et Informatique Appliquées aux Sciences Humaines et Sociales)**
            - Perception and motor control (3rd year degree, 10h)
        - **STAPS (Sciences et Techniques des Activités Physiques et Sportives)**
            - Neuropsychology and motor control (5th year degree, 4h)
            - Motivation and sport (5th year degree, 6h)
- **2015-2016**
    - **Psychology**
        - Cognitive Psychology (2nd year degree, 18h)
        - Neurosciences (3rd year degree, 18h)
        - Neurocognition (3rd year degree, 10h)
    - **MIASHS (Mathématiques et Informatique Appliquées aux Sciences Humaines et Sociales)**
        - Neuropsychology (2nd year degree, 2h)
    - **STAPS (Sciences et Techniques des Activités Physiques et Sportives)**
        - Neuropsychology and motor control (5th year degree, 4h)
        - Positive Psychology, well-being and pleasure (5th year degree, 3h)
- **2014-2015**
    - **Psychology**
        - Neurocognition (3rd year degree, 10h)
        - Neuropsychology (4th year degree, 2h)
    - **MIASHS (Mathématiques et Informatique Appliquées aux Sciences Humaines et Sociales)**
        - Experimental research (1st year degree, 10h)
        - Neurocognition (2nd year degree, 10h)
    - **STAPS (Sciences et Techniques des Activités Physiques et Sportives)**
        - Neuropsychology and motor control (5th year degree, 4h)
    - **SHS (Sciences Humaines et Sociales)**
    - Research design initiation (1st year degree, 36h)

UNDERGRADUATE STUDENTS CO-SUPERVISION

- **2016-2017**
    - Motor imagery and Tolerance of exercise intensity (3rd year degree)
- **2015-2016:**
    - Physical activity, Music and Tolerance of exercise intensity (3rd year degree)

    - Motor planning, Physical Activity and Tolerance of exercise intensity (4^{th} year degree)
- **2014-2015 :**
    - Motor planning, Physical Activity and Tolerance of exercise intensity (two 3^{rd} year degree)
    - French validation of the PRETIE-Q (3^{rd} year degree)
    - Physical activity, Pleasure and Tolerance of exercise intensity (Master 1 degree)
- **2013-2014 :**
    - The use of physical practice in psychiatry and rehabilitation centers (two 5^{th} year degree)

References

Abbiss, C. R., Peiffer, J. J., Meeusen, R., & Skorski, S. (2015). Role of Ratings of Perceived Exertion during Self-Paced Exercise: What are We Actually Measuring? *Sports Medicine (Auckland, N.Z.)*, *45*(9), 1235–1243.

American College of Sports Medicine, Thompson, W. R., Gordon, N. F., & Pescatello, L. S. (2010). *ACSM's guidelines for exercise testing and prescription*. Philadelphia: Lippincott Williams & Wilkins.

Annesi, J. (2003). Effects of a cognitive behavioral treatment package on exercise attendance and drop out in fitness centers. *European Journal of Sport Science*, *3*(2), 1–16.

Arnsten, A. F. T., & Robbins, T. W. (2002). Neurochemical modulation of prefrontal cortical function in humans and animals. In D. T. Stuss, & R. T. Knights (Eds.), *Principles of frontal lobe function* (pp. 51 – 84). New York : Oxford University, Press.

Audiffren, M. (2009). Acute exercise and psychological functions. In T. McMorris, P. Tomporowski, & M. Audiffren (Eds.), *Exercise and Cognitive Function* (pp. 2-39). Hoboken, NJ: Wiley-Blackwell.

Audiffren, M. (2016) The Reticular – Activating Hypofrontality (RAH) Model of Acute Exercise : Current Data and Future Perspectives. In T. McMorris. (Ed.), *Exercise – Cognition Interaction : New perspective* (pp 147 – 166). Academic Press.

Audiffren, M., & André, N. (2015). The strength model of self-control revisited: Linking acute and chronic effects of exercise on executive functions. *Journal of Sport and Health Science*, *4*(1), 30–46.

Backhouse, S. H., Ekkekakis, P., Bidle, S. J. H., Foskett, A., & Williams, C. (2007). Exercise makes people feel better but people are inactive: paradox or artifact? *Journal of Sport & Exercise Psychology*, *29*(4), 498–517.

Bamidis, P. D., Fissler, P., Papageorgiou, S. G., Zilidou, V., Konstantinidis, E. I., Billis, A. S., … Kolassa, I.-T. (2015). Gains in cognition through combined cognitive and physical training: the role of training dosage and severity of neurocognitive disorder. *Frontiers in Aging Neuroscience*, 152.

Barkley, R. A. (2012). Executive functions: What they are, how they work, and why they evolved. New York, NY: Guilford Press.

Bartolo, A., Carlier, M., Hassaini, S., Martin, Y., & Coello, Y. (2014). The perception of peripersonal space in right and left brain damage hemiplegic patients. *Frontiers in Human Neuroscience, 8*.

Barton, R. A. (2012). Embodied cognitive evolution and the cerebellum. *Phil. Trans. R. Soc. B*, *367*(1599), 2097–2107.

Batson, C. D., Shaw, L.L., & Oleson, K.C. (1992). Differentiating affect, mood and emotion : Toward functionally based conceptual distinctions. In M.S. Clark (Ed.), Review of personality and social psychology (Vol. 13, pp. 294 – 326). Newbury Park, CA : Sage.

Best, J. R., Nagamatsu, L. S., & Liu-Ambrose, T. (2014). Improvements to executive function during exercise training predict maintenance of physical activity over the following year. *Frontiers in Human Neuroscience*, *8*.

Blair, C., & Ursache, A. (2011). A bidirectional theory of executive functions and self-regulation. Retrieved from https://nyuscholars.nyu.edu/en/publications/a-bidirectional-theory-of-executive-functions-and-self-regulation

Blair, S. N. (2009). Physical inactivity: the biggest public health problem of the 21st century. *British Journal of Sports Medicine*, *43*(1), 1–2.

Borg, G. (1998). *Borg's perceived exertion and pain scales* (Vol. viii). Champaign, IL, US: Human Kinetics.

Bradt, J., Goodill, S.W. & Dileo, C. (2011) Dance:movement therapy for improving psychological and physical outcomes in cancer patients. *Cochrane Database of Systematic Reviews 2011*, Issue 10. Art. No:CD0077103

Buckley, J., Cohen, J. D., Kramer, A. F., McAuley, E., & Mullen, S. P. (2014a). Cognitive control in the self-regulation of physical activity and sedentary behavior. *Frontiers in Human Neuroscience, 8*, 747.

Buckley, J., Cohen, J. D., Kramer, A. F., McAuley, E., & Mullen, S. P. (2014b). Cognitive control in the self-regulation of physical activity and sedentary behavior. *Frontiers in Human Neuroscience, 8*, 747.

Burzynska, A. Z., Jiao, Y., Knecht, A. M., Fanning, J., Awick, E. A., Chen, T., … Kramer, A. F. (2017). White Matter Integrity Declined Over 6-Months, but Dance Intervention Improved Integrity of the Fornix of Older Adults. *Frontiers in Aging Neuroscience*, *9*.

Buss, A. T., & Spencer, J. P. (2017). Changes in frontal and posterior cortical activity underlie the early emergence of executive function. *Developmental Science*.

Cabanac, M. (1979). Sensory pleasure. *The Quarterly Review of Biology*, *54*(1), 1–29.

Carlier, M., Delevoye-Turrell, Y. (2017). Tolerance to exercise intensity modulates pleasure when exercising in music: The upsides of acoustic energy for High Tolerant individuals. *PLOS ONE*, *12*(3), e0170383.

Carver, C. S, Sheier, M. F. (1998). *On the Self-Regulation of Behavior*. Cambridge University Press.

Carver, S.C., Johnson, S.L., Joorman, J., & M.F., Scheier (2015). An Evolution Vieew of the Structure of Self-Regulation. In G. H. E. Gendolla, M. Tops, & S. L. Koole (Eds), H*andbook of Biobehavioral Approaches to Self-Regulation*. (pp. 9 – 23). Springer.

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports*, *100*(2), 126–131.

Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Research*, *1453*, 87–101.

Charles J. Hardy, W. J. R. (1989). Not what, but how one feels: The measurement of affect during exercise. *Journal of Sport & Exercise Psychology*, and 90% of maximum oxygen consumption.

Cisek, P., & Kalaska, J. F. (2010). Neural mechanisms for interacting with a world full of action choices. *Annual Review of Neuroscience*, *33*, 269–298.

Colcombe, S. J., Kramer, A. F., McAuley, E., Erickson, K. I., & Scalf, P. (2004). Neurocognitive aging and cardiovascular fitness: recent findings and future directions. *Journal of Molecular Neuroscience: MN*, *24*(1), 9–14.

Colcombe, S., & Kramer, A. F. (2003). Fitness Effects on the Cognitive Function of Older Adults A Meta-Analytic Study. *Psychological Science*, *14*(2), 125–130.

Colley, R. C., Garriguet, D., Janssen, I., Craig, C. L., Clarke, J., & Tremblay, M. S. (2011). Physical activity of Canadian adults: accelerometer results from the 2007 to 2009 Canadian

Health Measures Survey. *Health Reports*, *22*(1), 7–14.

Cools, R., & D'Esposito, M. (2011). Inverted-U-shaped dopamine actions on human working memory and cognitive control. *Biological Psychiatry*, *69*(12), e113-125.

Coquart, J. B., Garcin, M., Parfitt, G., Tourny-Chollet, C., & Eston, R. G. (2014). Prediction of Maximal or Peak Oxygen Uptake from Ratings of Perceived Exertion. *Sports Medicine (Auckland, N.Z.)*.

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., … Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381–1395.

Daly, M., McMinn, D., & Allan, J. L. (2014). A bidirectional relationship between physical activity and executive function in older adults. *Frontiers in Human Neuroscience*, *8*.

Desmond, J. E., Gabrieli, J. D., Wagner, A. D., Ginier, B. L., & Glover, G. H. (1997). Lobular patterns of cerebellar activation in verbal working-memory and finger-tapping tasks as revealed by functional MRI. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *17*(24), 9675–9685.

Diamond, A. (2000). Close Interrelation of Motor Development and Cognitive Development and of the Cerebellum and Prefrontal Cortex. *Child Development*, *71*(1), 44–56.

Dietrich, A., & Audiffren, M. (2011). The reticular-activating hypofrontality (RAH) model of acute exercise. *Neuroscience & Biobehavioral Reviews*, *35*(6), 1305–1325.

Dietrich, A., & Sparling, P. B. (2004). Endurance exercise selectively impairs prefrontal-dependent cognition. *Brain and Cognition*, *55*(3), 516–524.

Dishman, R. K., & Buckworth, J. (1996). Increasing physical activity: a quantitative synthesis. *Medicine and Science in Sports and Exercise*, *28*(6), 706–719.

Donchin, E., & Coles, M. G. H. (1988). Is the P300 Component a Manifestation of Context Updating? *Behavioral and Brain Sciences*, *11*(3), 357.

Ekkekakis, P. (2003). Pleasure and displeasure from the body: Perspectives from exercise. *Cognition & Emotion*, *17*(2), 213–239.

Ekkekakis, P. (2013). *The Measurement of Affect, Mood, and Emotion: A Guide for Health-Behavioral Research*. Cambridge University Press.

Ekkekakis, P. (2013). Physical activity as a mental health intervention in the era of managed care: A rationale. In P. Ekkekakis (Ed.), *Routledge handbook of physical activity and mental health* (pp. 1-32). New York: Routledge

Ekkekakis, P., & Acevedo, E.O. (2006). Affective responses to acute exercise: Toward a psychobiological dose-response model. In E.O. Acevedo & P. Ekkekakis (Eds.), Psychobiology of physical activity (pp. 91-109). Champaign, IL: Human Kinetics.

Ekkekakis, P., Hall, E. E., & Petruzzello, S. J. (2005). Some like it vigorous: measuring individual differences in the preference for and tolerance of exercise intensity. *J. Sport Exerc. Psychol*.

Ekkekakis, P., Lind, E., & Joens-Matre, R. R. (2006). Can self-reported preference for exercise intensity predict physiologically defined self-selected exercise intensity? *Research Quarterly for Exercise and Sport*, *77*(1), 81–90.

Ekkekakis, P., Parfitt, G., & Petruzzello, S. J. (2011). The pleasure and displeasure people feel when they exercise at different intensities: decennial update and progress towards a tripartite rationale for exercise intensity prescription. *Sports Medicine (Auckland, N.Z.)*, *41*(8), 641–671.

Ekkekakis, P., Thome, J., Petruzzello, S. J., & Hall, E. E. (2008). The Preference for and Tolerance of the Intensity of Exercise Questionnaire: a psychometric evaluation among college women. *Journal of Sports Sciences*, *26*(5), 499–510.

Erickson, K. I., Banducci, S. E., Weinstein, A. M., Macdonald, A. W., 3rd, Ferrell, R. E., Halder, I., … Manuck, S. B. (2013). The brain-derived neurotrophic factor Val66Met polymorphism moderates an effect of physical activity on working memory performance. *Psychological Science*, *24*(9), 1770–1779.

Eston, R. (2012). Use of ratings of perceived exertion in sports. *Int J Sports Physiol Perform*, *7*(2), 175–182.

Eston, R., Evans, H., Faulkner, J., Lambrick, D., Al-Rahamneh, H., & Parfitt, G. (2012). A perceptually regulated, graded exercise test predicts peak oxygen uptake during treadmill exercise in active and sedentary participants. *European Journal of Applied Physiology*, *112*(10), 3459–3468.

Eston, R. G., & Williams, J. G. (1988). Reliability of ratings of perceived effort regulation of exercise intensity. *British Journal of Sports Medicine*, *22*(4), 153–155.

Etnier, J. (2008). Interrelationships of Exercise, Mediator Variables, and Cognition. In W. W. Spirduso, L. W. Poon, & W. Chodzkio-Zajko (Eds), *Exercise and Its Mediating Effects on Cognition*. (pp. 13 – 30)- Human Kinetics.

Etnier, J. L., Nowell, P. M., Landers, D. M., & Sibley, B. A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews*, *52*(1), 119–130.

Eurobarometer (2010). Sport and Physical Activity.

Feriche, B., Chicharro, J. L., Vaquero, A. F., Pérez, M., & Lucía, A. (1998). The use of a fixed value of RPE during a ramp protocol. Comparison with the ventilatory threshold. *The Journal of Sports Medicine and Physical Fitness*, *38*(1), 35–38.

Fox, K. R. (1999). The influence of physical activity on mental well-being. *Public Health Nutrition*, *2*(3A), 411–418.

Fox, K. R., Boutcher, S. H., Faulkner, G. E., & Biddle, S. (2000). The case for exercise in the promotion of mental health and psychological well-being. In S. J. H. Biddle, K. R. Fox, & S. H. Boutcher (Eds.), *Physical activity and psychological well-being* (pp. 1–9). London: Routledge.

Frijda, N. H. (1986). *The Emotions*. Cambridge University Press.

Frijda, N. H. (1988). The laws of emotion. *The American Psychologist*, *43*(5), 349–358.

Gardner, H. (1993) Frames of Mind; The Theory of Multiple Intelligences (2nd end). New York: Basic Books.

Gendolla, G. H. E., Tops, M., & Koole, S. L. (2015). Introduction : Grounding Self-Regulation in the Brain and Body. In G. H. E. Gendolla, M. Tops, & S. L. Koole (Eds), H*andbook of Biobehavioral Approaches to Self-Regulation*. (pp. 1 – 6). Springer.

Gottwald, J. M., Achermann, S., Marciszko, C., Lindskog, M., & Gredebäck, G. (2016). An

Embodied Account of Early Executive-Function Development. *Psychological Science*, *27*(12), 1600–1610.

Gray, E., & Watson, D. (2007). Assessing positive and negative affect via self-report. In J. A. Coan, & J. J. B. Allen, (Eds), *Handbook of Emotion Elicitation and Assessment*. (pp 171 – 183). Oxford University Press, USA.

Hall, E. E., Petruzzello, S. J., Ekkekakis, P., Miller, P. C., & Bixby, W. R. (2014). Role of self-reported individual differences in preference for and tolerance of exercise intensity in fitness testing performance. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *28*(9), 2443–2451.

Hall, P. A., & Fong, G. T. (2015). Temporal self-regulation theory: a neurobiologically informed model for physical activity behavior. *Frontiers in Human Neuroscience*, *9*.

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., & Ekelund, U. (2012). Global physical activity levels: surveillance progress, pitfalls, and prospects. *The Lancet*, *380*(9838), 247–257.

Haskell, W. L., Lee, I.-M., Pate, R. R., Powell, K. E., Blair, S. N., Franklin, B. A., … Bauman, A. (2007). Physical Activity and Public Health. Updated Recommendation for Adults From the American College of Sports Medicine and the American Heart Association. *Circulation*.

Hayes, S., Donnellan, C., & Stokes, E. (2013). Associations between executive function and physical function poststroke: a pilot study. *Physiotherapy*, *99*(2), 165–171.

Hefferon, K. (2013). *Positive Psychology and the Body: The Somatopsychic Side to Flourishing*. McGraw-Hill Education (UK).

Hefferon, K., & Boniwell, I. (2011). *Positive Psychology: Theory, Research and Applications*. McGraw-Hill Education (UK).

Herring, M. P., Sailors, M. H., & Bray, M. S. (2014). Genetic factors in exercise adoption, adherence and obesity. *Obesity Reviews: An Official Journal of the International Association for the Study of Obesity*, *15*(1), 29–39.

Heyes, C. (2012). New thinking: the evolution of human cognition. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1599), 2091–2096.

Hillman, C. H., Snook, E. M., & Jerome, G. J. (2003). Acute cardiovascular exercise and executive control function. *International Journal of Psychophysiology*, *48*(3), 307–314.

Huppert, F.A. (2005). Positive mental health in individuals and populations. In F.A. Huppert, B. Keverne, & N. Baylis (Eds.), *The Science of Well-being* (pp. 307-340), Oxford: Owford University Press.

Huppert, F.A. (2009) A new approach to reducing disorder and improving well-being. *Perspectives on Psychological Scienc*e, *4*(1); 108-11

Inserm (2008). Activité physique. Contextes et effets sur la santé.

Jeannerod, M. (2006). *Motor cognition what actions tell the self*. Oxford; New York: Oxford University Press.

Jekauc, D. (2015). Enjoyment during Exercise Mediates the Effects of an Intervention on Exercise Adherence. *Psychology*, *6*(1), 48.

Kattenstroth, J.-C., Kalisch, T., Holt, S., Tegenthoff, M., & Dinse, H. R. (2013). Six months of dance intervention enhances postural, sensorimotor, and cognitive performance in elderly without affecting cardio-respiratory functions. *Frontiers in Aging Neuroscience*, *5*.

Katzmarzyk, P. T., & Lee, I.-M. (2012). Sedentary behaviour and life expectancy in the USA: a cause-deleted life table analysis. *BMJ Open*, *2*(4), e000828.

Kempermann, G., Fabel, K., Ehninger, D., Babu, H., Leal-Galicia, P., Garthe, A., & Wolf, S. A. (2010). Why and How Physical Activity Promotes Experience-Induced Brain Plasticity. *Frontiers in Neuroscience*, *4*.

Keyes, C.L.M. (2002) The mental health continuum: from languishing to flourishing life. *Journal of Mental Health and Social Behaviour*, 43:207-22

Kline, R. B. (2011). *Principles and Practice of Structural Equation Modeling*. Guilford Publications.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, *38*(3), 557–577.

Koziol, L. F., Budding, D. E., & Chidekel, D. (2011). From Movement to Thought: Executive Function, Embodied Cognition, and the Cerebellum. *The Cerebellum*, *11*(2), 505–525.

Koziol, L. F., & Lutz, J. T. (2013). From movement to thought: the development of executive function. *Applied Neuropsychology. Child*, *2*(2), 104–115.

Kutas, M., McCarthy, G., & Donchin, E. (1977). Augmenting mental chronometry: the P300 as a measure of stimulus evaluation time. *Science (New York, N.Y.)*, *197*(4305), 792–795.

Lauenroth, A., Ioannidis, A. E., & Teichmann, B. (2016). Influence of combined physical and cognitive training on cognition: a systematic review. *BMC Geriatrics*, *16*.

Lind, E., Joens-Matre, R. R., & Ekkekakis, P. (2005). What intensity of physical activity do previously sedentary middle-aged women select? Evidence of a coherent pattern from physiological, perceptual, and affective markers. *Preventive Medicine*, *40*(4), 407–419.

Linley, A. (2009). Positive Psychology (History). In S. J. Lopez (Ed.), *The Encyclopedia of Positive Psychology* (pp. 1–742). Wiley-Blackwell.

Loeffler, J., Raab, M., & Cañal-Bruland, R. (2016). A Lifespan Perspective on Embodied Cognition. *Frontiers in Psychology*, *7*, 845.

Loring, D. W., & Meador, K. J. (1999). *INS Dictionary of Neuropsychology*. Oxford University Press.

MacMahon, C., Schücker, L., Hagemann, N., & Strauss, B. (2014). Cognitive fatigue effects on physical performance during running. *Journal of Sport & Exercise Psychology*, *36*(4), 375–381.

Magliero, A., Bashore, T. R., Coles, M. G., & Donchin, E. (1984). On the dependence of P300 latency on stimulus evaluation processes. *Psychophysiology*, *21*(2), 171–186.

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, *106*(3), 857–864.

McKenna, M. J., & Hargreaves, M. (2008). Resolving fatigue mechanisms determining exercise performance: integrative physiology at its finest! *Journal of Applied Physiology (Bethesda, Md.: 1985)*, *104*(1), 286–287.

Michalec, B., Keyes, C., and Nalkur, S. (2009). Human flourishing. In S. Lopez (Ed.), The Encyclopedia of Positive Psychology (pp. 391-394). Chichester: Blackwell Publishing Ltd.

Milne, S., Orbell, S., & Sheeran, P. (2002). Combining motivational and volitional interventions to promote exercise participation: Protection motivation theory and implementation intentions. *British Journal of Health Psychology, 7*(2), 163–184.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100.

Mogil, J. S. (1999). The genetic mediation of individual differences in sensitivity to pain and its inhibition. *Proceedings of the National Academy of Sciences of the United States of America*, *96*(14), 7744–7751.

Mohiyeddini, C., Pauli, R., & Bauer, S. (2009). The role of emotion in bridging the intention–behaviour gap: The case of sports participation. *Psychology of Sport and Exercise*, *10*(2), 226–234.

Monsell, S. (1996). Control of mental processes. In V. Bruce (Ed.), *Unsolved mysteries of the mind: Tutorial essays in cognition* (pp. 93–148). Hove, UK: Erlbaum.

Morgan, W.P. (1981). Psychological benefits of physical activity. In F.J. Nagle & H.J. Montoye (Eds.), *Exercise in health and disease* (pp. 299–314). Springfield, IL: Charles C. Thomas.

Morris, N., & Jones, D. M. (1990). Memory updating in working memory: The role of the central executive. *British Journal of Psychology*, **81,** 111–121.

Mullen, S. P., & Hall, P. A. (2015). Editorial: Physical activity, self-regulation, and executive control across the lifespan. *Frontiers in Human Neuroscience, 9*, 614.

Müller, P., Rehfeld, K., Schmicker, M., Hökelmann, A., Dordevic, M., Lessmann, V., …

Müller, N. G. (2017). Evolution of Neuroplasticity in Response to Physical Activity in Old Age: The Case for Dancing. *Frontiers in Aging Neuroscience, 9*.

Mutrie, N., & Faulkner, G. (2004). Physical activity : positive psychology in motion. In P. A. Linley & S. Joseph (Eds.), *Positive Psychology in Practice*. John Wiley & Sons Inc.

Neubert, F.-X., Mars, R. B., Buch, E. R., Olivier, E., & Rushworth, M. F. S. (2010). Cortical and subcortical interactions during action reprogramming and their related white matter pathways. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(30), 13240–13245.

Oja, P., & Borms, J. (2004). *Health Enhancing Physical Activity*. Meyer & Meyer Sport.

Oswald, W. D., Gunzelmann, T., Rupprecht, R., & Hagen, B. (2006). Differential effects of single versus combined cognitive and physical training with older adults: the SimA study in a 5-year perspective. *European Journal of Ageing*, *3*(4), 179. https://doi.org/10.1007/s10433-006-0035-z

Otero, T. M., & Barker, L. A. (2014). The Frontal Lobes and Executive Functioning. In *Handbook of Executive Functioning* (pp. 29–44). Springer, New York, NY.

Pageaux, B., Lepers, R., Dietz, K. C., & Marcora, S. M. (2014). Response inhibition impairs subsequent self-paced endurance performance. *European Journal of Applied Physiology*, *114*(5), 1095–1105.

Pageaux, B., Marcora, S. M., & Lepers, R. (2013). Prolonged mental exertion does not alter neuromuscular function of the knee extensors. *Medicine and Science in Sports and Exercise*, *45*(12), 2254–2264.

Panksepp, J. (1998). The periconscious substrates of consciousness: affective states and the evolutionary origins of the self. *Journal of Consciousness Studies*, *5*(5–6), 566–582.

Parfitt, G., Rose, E. A., & Burgess, W. M. (2006). The psychological and physiological responses of sedentary individuals to prescribed and preferred intensity exercise. *British Journal of Health Psychology*, *11*(Pt 1), 39–53.

Pesce, C. (2016). « Cogito ergo sum » or « ambulo ergo sum » ? New perspectives in Developmental Exercise and Cognition Research. In T. McMorris. (Ed.), *Exercise – Cognition Interaction : New perspective* (pp 251 – 282). Academic Press.

Piaget, J. (1936). *Origins of Intelligence in the Child*. London: Routledge & Kegan Paul.

Piaget, J., Inhelder, B., (1966à. *L'image mentale chez l'enfant: étude sur le développement des représentations imagées.* Paris: Presses Univ. de France.

Polich, J. (1987). Task difficulty, probability, and inter-stimulus interval as determinants of P300 from auditory stimuli. *Electroencephalography and Clinical Neurophysiology*, *68*(4), 311–320.

Polich, J., & Heine, M. R. (1996). P300 topography and modality effects from a single-stimulus paradigm. *Psychophysiology*, *33*(6), 747–752.

Polich, J., & Lardon, M. T. (1997). P300 and long-term physical exercise. *Electroencephalography and Clinical Neurophysiology*, *103*(4), 493–498.

Reimers, C. D., Knapp, G., & Reimers, A. K. (2012). Does Physical Activity Increase Life Expectancy? A Review of the Literature. *Journal of Aging Research*, *2012*, e243958.

Roebers, C. M., Röthlisberger, M., Neuenschwander, R., Cimeli, P., Michel, E., & Jäger, K. (2014). The relation between cognitive and motor performance and their relevance for children's transition to school: A latent variable approach. *Human Movement Science*, *33*, 284–297.

Rooks, C. R., Thom, N. J., McCully, K. K., & Dishman, R. K. (2010). Effects of incremental exercise on cerebral oxygenation measured by near-infrared spectroscopy: a systematic review. *Progress in Neurobiology*, *92*(2), 134–150.

Rose, E. A., & Parfitt, G. (2008). Can the feeling scale be used to regulate exercise intensity? *Medicine and Science in Sports and Exercise*, *40*(10), 1852–1860.

Rosenbaum, D. A., Carlson, R. A., & Gilmore, R. O. (2001). Acquisition of intellectual and perceptual-motor skills. *Annual Review of Psychology*, *52*, 453–470.

Schneider, M., & Graham, D. (2009). Personality, physical fitness, and affective response to exercise among adolescents. *Medicine and Science in Sports and Exercise*, *41*(4), 947–955.

Schücker, L., Knopf, C., Strauss, B., & Hagemann, N. (2014). An internal focus of attention is not always as bad as its reputation: how specific aspects of internally focused attention do not hinder running efficiency. *Journal of Sport & Exercise Psychology*, *36*(3), 233–243.

Schuna, J. M., Johnson, W. D., & Tudor-Locke, C. (2013). Adult self-reported and objectively monitored physical activity and sedentary behavior: NHANES 2005–2006. *International Journal of Behavioral Nutrition and Physical Activity*, *10*(1), 126.

Schutzer, K. A., & Graves, B. S. (2004). Barriers and motivations to exercise in older adults. *Preventive Medicine*, *39*(5), 1056–1061. https://doi.org/10.1016/j.ypmed.2004.04.003

Seamans, J. K., & Yang, C. R. (2004). The principal features and mechanisms of dopamine modulation in the prefrontal cortex. *Progress in Neurobiology*, *74*(1), 1–58.

Seligman, M. E., & Csikszentmihalyi, M. (2000). Positive psychology. An introduction. *The American Psychologist*, *55*(1), 5–14.

Shaulov, N., & Lufi, D. (2009). Music and light during indoor cycling. *Perceptual and Motor Skills*, *108*(2), 597–607.

Shumaker, S. A., Ockene, J. K., & Riekert, K. A. (2008). *The Handbook of Health Behavior Change, Third Edition*. Springer Publishing Company.

Slattery, M. L., & Jacobs, D. R., Jr. (1988). Physical fitness and cardiovascular disease mortality. The US Railroad Study. *American Journal of Epidemiology*, *127*(3), 571–580.

Smirmaul, B. P. C., Ekkekakis, P., Teixeira, I. P., Nakamura, P. M., & Kokubun, E. (2015). Preference for and Tolerance of the Intensity of Exercise questionnaire: Brazilian Portuguese version. *Brazilian Journal of Kinanthropometry and Human Performance*, *17*(5), 550–564.

Smith, L. B. (2005). Action alters shape categories. *Cognitive Science*, *29*(4), 665–679.

Smith, M. R., Coutts, A. J., Merlini, M., Deprez, D., Lenoir, M., & Marcora, S. M. (2016). Mental Fatigue Impairs Soccer-Specific Physical and Technical Performance. *Medicine and Science in Sports and Exercise*, *48*(2), 267–276.

Smith, M. R., Marcora, S. M., & Coutts, A. J. (2015). Mental Fatigue Impairs Intermittent Running Performance. *Medicine and Science in Sports and Exercise*, *47*(8), 1682–1690.

Stojiljković, S., Nesić, D., Mazić, S., Popović, D., Mitrović, D., & Mitić, D. (2004). [Determination of ventilatory threshold based on subjective rating of perceived exertion]. *Srpski Arhiv Za Celokupno Lekarstvo*, *132*(11–12), 409–413.

Strassel, J.K., Cherkin, D.C., Steuten, L., Sherman, K.J. and Vrijhoef, H.J. (2011) A systematic review of the evidence for the effectiveness of dance therapy. Alternative Therapies in Health and Medicine, *17*(3):50-9

Swain, R. A., Harris, A. B., Wiener, E. C., Dutka, M. V., Morris, H. D., Theien, B. E., … Greenough, W. T. (2003). Prolonged exercise induces angiogenesis and increases cerebral blood volume in primary motor cortex of the rat. *Neuroscience*, *117*(4), 1037–1046.

Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., & Kawashima, R. (2013). Brain structures associated with executive functions during everyday events in a non-clinical sample. *Brain Structure & Function*, *218*(4), 1017–1032.

Teixeira, P. J., Carraça, E. V., Markland, D., Silva, M. N., & Ryan, R. M. (2012). Exercise, physical activity, and self-determination theory: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 78.

Tomkins, S. (1962). Affect, imagery, consciousness (Vol. 1). New York :Springer

Tomporowski, P. D. (2008). Cognitive Energetics and Aging. In W. W. Spirduso, L. W. Poon, & W. Chodzkio-Zajko (Eds), *Exercise and Its Mediating Effects on Cognition*. (pp. 85 – 110)- Human Kinetics.

Trost, S. G., Owen, N., Bauman, A. E., Sallis, J. F., & Brown, W. (2002). Correlates of adults' participation in physical activity: review and update. *Medicine and Science in Sports and Exercise*, *34*(12), 1996–2001.

van der Fels, I. M. J., te Wierike, S. C. M., Hartman, E., Elferink-Gemser, M. T., Smith, J., & Visscher, C. (2015). The relationship between motor skills and cognitive skills in 4–16 year old typically developing children: A systematic review. *Journal of Science and Medicine in Sport*, *18*(6), 697–703. https://doi.org/10.1016/j.jsams.2014.09.007

Van Landuyt, L. M., Ekkekakis, P., Hall, E. E., & Petruzzello, S. J. (2000). Throwing the mountains into the lake: On the perils of nomothetic conceptions of the exercise–affect relationship. *Journal of Sport & Exercise Psychology, 22*(3), 208–234.

van Praag, H., Christie, B. R., Sejnowski, T. J., & Gage, F. H. (1999). Running enhances neurogenesis, learning, and long-term potentiation in mice. *Proceedings of the National Academy of Sciences of the United States of America*, *96*(23), 13427–13431. Retrieved from

van Rooijen, M., Verhoeven, L., Smits, D.-W., Ketelaar, M., Becher, J. G., & Steenbergen, B. (2012). Arithmetic performance of children with cerebral palsy: the influence of cognitive and motor factors. *Research in Developmental Disabilities*, *33*(2), 530–537.

Viljoen, M., & Panzer, A. (2007). The central noradrenergic system: an overview. *African Journal of Psychiatry*, *10*(3), 135–141.

Voss, M. W., Prakash, R. S., Erickson, K. I., Basak, C., Chaddock, L., Kim, J. S., … Kramer, A. F. (2010). Plasticity of Brain Networks in a Randomized Intervention Trial of Exercise Training in Older Adults. *Frontiers in Aging Neuroscience, 2*.

Wang, L., & Zhang, Y. (2016). An extended version of the theory of planned behaviour: the role of self-efficacy and past behaviour in predicting the physical activity of Chinese adolescents. *Journal of Sports Sciences, 34*(7), 587–597.

Wienke, B., & Jekauc, D. (2016). A Qualitative Analysis of Emotional Facilitators in Exercise. *Frontiers in Psychology, 7*.

Wolpert, D. M., Diedrichsen, J., & Flanagan, J. R. (2011). Principles of sensorimotor learning. *Nature Reviews. Neuroscience, 12*(12), 739–751.

Wong, P. (2011). Positive Psychology 2.0: towards a balanced interactive model of the good life. *Canadian Psychology*, *52*(2): 69-81.

World Health Organization (1946). The Constitution of the World Health Organisation.

World Health Organization (2003). *Investing in mental health*. Geneva, Switzerland: Author.

Zenko, Z., Ekkekakis, P., & Ariely, D. (2016). Can You Have Your Vigorous Exercise and Enjoy It Too? Ramping Intensity Down Increases Postexercise, Remembered, and Forecasted Pleasure. *Journal of Sport & Exercise Psychology*, *38*(2), 149–159.