A new decade for social changes
Working memory interventions via physical activity and ICTs: A strategic issue for the improvement of school students’ learning performance

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Abstract. Nowadays, there is a great need for schools to be transformed into more innovative learning environments with more innovative approaches to learning and teaching so as students to be allowed to develop their various skills and abilities to their fullest extent. Therefore, we present the role of physical activity and ICT-based interventions for working memory enhancement as a strategic issue for the improvement of students’ learning outcomes. According to research findings, multi-component exercise and ICT-based intervention programs can significantly contribute to the improvement of children’s and adolescents’ working memory and thus can have a positive effect on children’s and adolescents’ learning performance. Finally, this paper could trigger educators and policy-makers towards the ideal planning of innovative multi-component physical activity and ICT-based intervention programs and their incorporation into the school curriculum aiming at the working memory enhancement in children and adolescents and the improvement of their learning outcomes.

Keywords. working memory interventions, physical activity, ICTs, learning performance, school students, children, adolescents

1. Introduction

In today's society, the need to transform schools for the participation of young people becomes imperative. Therefore, schools should promote more innovative approaches to learning and teaching (Timperley, Kaser, & Halbert, 2014) so that all students’ learning needs are met (Drigas, Argyri, Vrettaros 2009). One such innovative approach could be the integration of ICT-based physical activity and working memory interventions into the school curriculum to enhance students’ working memory and thus improve their learning performance since, according to Gathercole, Lamont, and Alloway (2006), working memory is linked to academic learning.

Working memory constitutes a brain system responsible for the temporary storage and manipulation of the information necessary for language comprehension, learning, and reasoning, which are complex cognitive tasks (Baddeley, 1992; 2010). Chronic aerobic exercise can enhance children’s working memory capacity (Guiney & Machado, 2013), while highly intense and structured physical activities are especially relevant for working memory enhancement in adolescence (Lopez-Vicente, Garcia-Aymerich, Torrent-Pallicer, Forns,
Ibarluzea, Lertxundi, Gonzalez, Valera-Gran, Torrent, Dadvand, Vrijheid, & Sunyer, 2017). Notably, the use of ICTs, such as computer-based tools, mobile training apps, video games (Pappas, Drigas, Malli, & Kalpidi, 2018, Drigas et all 2004, 2009, 2013 Papoutsi, et all 2018), and serious games (Chaldogeridis & Tsiatsos, 2020) can significantly contribute to working memory enhancement.

In the current paper, we focus on the crucial role of physical activity and ICTs in school students’ working memory and present it as a strategic issue for their learning improvement. We chose to focus on physical activity and ICT-based interventions for the enhancement of school students’ working memory because school students’ way and quality of life are affected by today’s digitalization and sedentary lifestyles, which also have a profound impact on their learning progress.

More specifically, the rapid development of ICTs has led to computers becoming part of daily life (Drigas & Ioannidou, 2012, 2013; Player-Koro, 2012) and has pushed ICTs and computers into classrooms at all educational levels (Player-Koro, 2012, Kefalis & Drigas 2019). In fact, technologies within the domain of interactive, remote and online science such as interactive whiteboards and related applications are extensively adopted in education’s everyday life (Drigas & Papanastasiou, 2014).

In addition, today’s daily life is characterized by decreased or low physical activity levels because of the increased use of motorized transport and screens for work, education and recreation. Research findings indicate that in children and adolescents, physical activity, which is defined as “any bodily movement produced by skeletal muscles that requires energy expenditure”, can improve mental health and cognitive functions (WHO, 2021), such as working memory. Physical activity’s positive impact on cognitive functions is based on several mechanisms, including angiogenesis, oxygen saturation, glucose delivery, cerebral blood flow, and neurotransmitter levels (Diamond, 2015).

This paper also reflects an effort to raise reader’s awareness of the significance of children’s and adolescents’ daily physical activity engagement in school environments and highlights the need for multi-component exercise and ICT-based working memory intervention programs to be incorporated into the school curriculum targeting the effective enhancement of working memory in children and adolescents and thus their positive learning outcomes.

2. Working memory in children and adolescents

Working memory is a brain system responsible for the temporary storage and manipulation of the information necessary for language comprehension, learning, and reasoning, which are complex cognitive tasks (Baddeley, 1992; 2010). Working memory is inextricably linked to attention (Angelopoulou, & Drigas, 2021), but is distinguished from short-term memory, because these two memory systems represent different cognitive functions (Aben, Stapert & Blokland, 2012). More specifically, short-term memory is responsible for storing information for a short period of time (e.g., remembering a phone number), while working memory refers to handling information during a complex cognitive process (e.g., remembering numbers while reading a paragraph) (Goldstein, 2011).

Many researchers present working memory as a mental laboratory (Μασούρα, 2010) that stores and manipulates information for short periods of time (Baddeley, 1986; Μασούρα, 2010; Gathercole & Alloway, 2007). It is also involved in almost every activity of daily life and is subjected to gradual changes during the period of 5 and 19 years of human development (Alloway & Alloway, 2013).
Only a small amount of information can working memory hold either abstract ideas or objects that can be counted (Cowan, 2014). It has been estimated that adults’ working memory capacity is in the range of 3 or 4 objects (Cowan, 2001; Luck & Vogel, 1998; see Cowan 2016, p. 7), while preschoolers and early elementary school children can maintain in their working memory 2 or 2.5 items (Cowan, Nugent, Elliott, Ponomarev, & Saults, 1999; Cowan, Elliott et al., 2005; Riggs, McTaggart, Simpson, & Freeman, 2006; Simmering, 2012; see Cowan 2016, p.7).

Working memory capacity increases during infancy but then regresses during childhood (Cowan 2016). The minimum age at which a reliable measurement of working memory can be made is 4 years (Alloway, Gathercole, & Kirkwood, 2016). Research has shown the existence of linear increase in the performance of the phonological loop, central executive, and visuo-spatial sketchpad from the age of 4 years to adolescence (Gathercole, Pickering, Ambridge & Wearing, 2004). During adolescence, working memory capacity is close to that of an adult and more than twice the working memory capacity of a four year old child (Gathercole et al., 2007).

Older children can hold more bits of information than younger children. More specifically, the child at the age of 4 years can recall 3 digits in a row, while at the age of 12 years the number of digits doubles and at the age of 16 years the range of digits reaches 7 to 8 digits (Hulme & Mackenzie, 1992, as cited in Dehn, 2008). Research findings suggest that recall-guided action for single units of spatial information develops until 11 to 12 years, and the ability to maintain and manipulate multiple spatial units develops until 13 to 15 years. These findings are related to the maturation of distinct prefrontal regions and the organization of the prefrontal cortex by level of processing (Luciana, Conklin, Hooper, & Yarger, 2005).

Furthermore, visual working memory ability continues to develop throughout adolescence. However, it cannot reach the corresponding adult level even at the age of 16. That indicates the U-shaped developmental row of visual working memory, according to which it approaches higher performance levels earlier in life. But then it declines during adolescence and rises again in adulthood (Isbell, Fukuda, Neville, & Vogel, 2015).

3. Working memory and school students’ learning performance

Working memory is closely associated with academic learning (Gathercole, Lamont, & Alloway, 2006). Learning might be assumed to be the formation of new concepts. These new concepts occur when existing concepts are joined or bound together. For the various types of concept formation, then, the cauldron is considered to be working memory, which is linked to fluid intelligence that is closely related to crystallized intelligence (Cowan, 2014).

Fluid intelligence refers to the ability to reason and to solve new problems independently of previously acquired knowledge (Carpenter, Just, & Shell, 1990), while crystallized intelligence refers to the type of intelligence that involves what an individual knows (Cowan, 2014). Good working memory, then, is critical to learning because a good working memory assists in problem-solving (hence fluid intelligence); fluid intelligence and working memory then assist in new learning (hence crystallized intelligence) (Cowan, 2014).

Several studies have shown that the majority of children with poor working memory are slow to learn in the areas of reading, maths and science, across both primary and secondary school years (see Gathercole et al., 2006). For children, reading comprehension is a complex activity and, once basic decoding skills have been sufficiently acquired and automated, it requires several cognitive processes, one of which is working memory (Carretti, Borella, Elosúa, Gómez-Veiga, & García-Madruga, 2017).
Poor phonological working memory (Nicolielo-Carrilho, Crenitte, Lopes-Herrera, & Hage, 2018) and poor verbal working memory can lead to poor reading performance (Giofrè, Donolato, & Mammearella, 2018), whereas poor working memory capacity (Mousavi, Badarudin, & Malt, 2012; Alamolhodaei, 2009; Alloway, 2006; Holmes & Adam, 2006; Swanson, 2004; Wilson & Swanson, 2001); in fact, poor visuo-spatial working memory can lead to poor mathematical performance (Giofrè et al., 2018).

Loosli, Buschkuehl, Perrig, and Jaeggi (2012) showed that working memory training improves school students’ reading abilities, while Söderqvist and Bergman Nutley (2015) claimed that working memory training can help optimize long term attainments in maths and reading. According to Carretti et al. (2017), training working memory and its executive processes during reading comprehension activities is a promising approach to sustaining reading comprehension. Notably, a study by Alloway, Bibile, and Lau (2013) demonstrated that computerized working memory training could lead to gains in academic performance.

4. Working memory interventions via physical activity and ICTs

4.1. The benefits of physical activity for children’s and adolescents’ working memory

Physical activity is defined as “any bodily movement produced by skeletal muscles that requires energy expenditure, which can be measured in kilocalories” (Caspersen, Powell, & Christenson, 1985). In the light of this definition, physical activity can be linked to organized physical activities (e.g., handball and football) and transportation (e.g., cycling and walking). Also, physical activity can be considered as part of domestic tasks, such as cleaning and carrying (Lahti, 2019).

Furthermore, physical activity can be subdivided into moderate (Caspersen et al., 1985), such as walking (Dencker, Thorsson, Karlsson, Lindén, Eiberg, Wollmer, & Andersen, 2006) and vigorous intensity (Caspersen et al., 1985), such as running (Dencker et al., 2006), and can be quantified using metabolic equivalents (METs) (Jetté, Sidney, & Blümchen, 1990). 1 MET is defined as the amount of oxygen consumed at rest, when sitting quietly, and equals to approximately 3.5 ml 02/kg/min (1.2 kcal/min for a 70-kg person) (Jetté et al., 1990). Two studies conducted by Dencker et al. (2006, 2008) defined 8-11 years old children’s moderate physical activity as 3-6 METs and their vigorous physical activity as > METs.

Physical activity has a positive effect on cognition as well as brain structure and function (Donnelly, Hillman, Castelli, Et nier, Lee, Tomporowski, Lam bourn e, & Szabo-Reed, 2016; Haverkamp, Wiersma, Vertess e, van Ewijk, Oosterlaan, & Hartman, 2020). Its impact on cognitive functions has been widely studied (Lambourne, 2006; Chacón-Cuberos, Zurita-Ortega, Ramírez-Granizo, & Castro-Sánchez, 2020). Such cognitive functions that benefit from physical activity are attention, memory, and concentration. It is noteworthy that physical activity tasks that feature higher cognitive demands and involve gross motor skills are more effective on cognitive performance (Chacón-Cuberos et al., 2020).

A study by López-Vicente et al. (2017) showed that low physical activity levels at preschool age could be associated with poorer working memory performance at primary school age. The same study also showed that low physical activity levels at primary school age are related to lesser working memory in adolescents, while highly intense and structured physical activities are especially relevant for working memory enhancement in adolescence.

Also, sedentary behavior, such as increased screen time, has detrimental effects on cognitive development during childhood (Carson, Kuzik, Hunter, Wiebe, Spence, Friedman, Tremblay, Slater, & Hinkley, 2015). Therefore, obese and overweight children have poor
working memory abilities (Christina, Sangeetha, Kumaresan, Varadharaju, & Hemachandrika, 2021) due to the fact that obesity, which is linked to an increased amount of time spent in sedentary behaviors (Sahoo, Sahoo, Choudhury, Sofi, Kumar, & Bhadoria, 2015), affects cognition through altering the brain structures and functions, as well as motor performance (Christina et al., 2021).

Furthermore, chronic physical activity interventions can have larger effect sizes on a broader range of cognitive outcomes in children and adolescents (Haapala, 2012; Haverkamp et al., 2020). In addition, response times, during information processing, inhibitory control and working memory tasks, are quicker in adolescents with a higher physical fitness, when compared to their low-fit counterparts (Williams, Cooper, Dring, Hatch, Morris, Sunderland, & Nevill, 2020).

However, despite the benefits of physical activity, globally, 81% of adolescents aged 11-17 years were insufficiently physically active in 2016. Notably, adolescent girls were less active than adolescent boys, with 85% vs. 78% not meeting WHO recommendations of at least 60 minutes of moderate to vigorous intensity physical activity per day (World Health Organization, 2020).

4.1.1. Physical activity-based working memory interventions

All the above benefits of physical activities for the working memory enhancement, as well as the WHO statistics regarding the physical activity rates in children and adolescents, confirm that the need for children’s and adolescents’ daily engagement in physical activity becomes imperative. According to Guiney and Machado (2013), chronic aerobic exercise can enhance children’s working memory capacity; in fact, Ludyga et al. (2018) showed that adolescents’ daily engagement in a short aerobic and coordinative exercise program following the school lunchtime break contributes to their working memory maintenance and task preparations.

In addition, by applying 10 weeks of $3 \times 45$ minutes of after-school cardiovascular exercise and a motor-demanding activity for preadolescent children, Koutsandréou, Wegner, Niemann, and Budde (2016) found a positive effect of both cardiovascular and motor exercises on working memory in preadolescent children.

Another intervention study by Lind, Geerten, Ørntoft, Madsen, Larsen, Dvorak, Ritz, and Krustrup (2018) also reported positive effects on working memory performance after an 11-week intervention, the “FIFA 11 for Health” for Europe program, which comprised small-sided football games, drills and on-pitch health education, and it combined cardiovascular exercise and motor and cognition demands. Moreover, this study showed that a physical activity program based on a well-established team game, such as football, can have a positive effect on cognitive performance in preadolescent children. It is noteworthy that Chen, Chen, Chu, Liu, and Chang (2017) observed that a multi-component exercise intervention involving a jump rope can positively affect obese children’s cognitive functions.

Of great interest is a study conducted by Ruiz-Ariza, CasusoSuarez-Manzano, and Martínez-López (2018), which reported positive effects of an 8-week intervention using the augmented reality game “Pokemon GO” on cognitive performance and sociability in adolescents aged 12-15 years. Augmented reality games allow players to interact with the world through their device’s camera (Lanham, 2017), contributing to increased physical activity (Ni, Hui, Li, Tam, Choy, Ma, Cheung, & Leung, 2019).

Finally, Chacón-Cuberos et al. (2020), considering the aforementioned studies of Chen et al. (2017), Lind et al. (2018), and Ruiz-Ariza et al. (2018), detected two basic requirements
for physical activity to generate positive effects on cognition. More specifically, the first lies in the load of the intervention performed, involving a minimum of 150 minutes per week of work, in which the intensity is moderate (Chen et al., 2017; Lind et al., 2018), while the second requirement is related to the cognitive demands of the task to be performed, that is, a cooperation sport with an opponent can contribute to more cognitive improvements (Ruiz-Ariza et al., 2018).

4.2. ICT-based working memory interventions

It is broadly agreed that Information and Communications Technology (ICT) can enhance students’ educational, social and cultural experiences (Drigas & Ioannidou, 2013) and can contribute effectively to the learning process (Drigas et al., 2013; Chaidi, Drigas, & Karagiannidis, 2021). The term “ICT” is defined as “the study, design, development, implementation, support or management of computer-based information systems in order information to be converted, stored, protected, processed and retrieved” (Shuja, 2009).

In the field of education the term “ICT” refers to all types of technological means used in teaching methods such as computers, tablets, interactive whiteboards (Galitskaya & Drigas, 2019), mobile applications (Drigas & Kokkalia, 2016; Karabatzaki, Stathopoulou, Kokkalia, Dimitriou, Loukeri, Economou, & Drigas, 2018), artificial intelligence (AI) applications (Drigas & Angelidakis, 2017), serious games (Kokkalia, Drigas, Economou, Roussos, & Choli, 2017).

Prolonged exposure to technology and media devices probably has a great impact on cognition (Alexopoulou, Batsou, & Drigas, 2020) that is the mental process of acquiring knowledge and understanding (Titilayo, 2016), with which working memory is fundamentally related (Bouchacourt & Buschman, 2019). Notably, computer-based tools, mobile training apps, and video games could significantly contribute to cognitive improvement (Pappas et al., 2018, 2019) and, thus, to working memory enhancement.

Taking into consideration that working memory is engaged during simultaneous processing and storage of information, ICT use facilitates working memory capacity amplification because it provides the necessary amount of repeated practice in simultaneous processing and storage of information on a massive scale (García, Nussbaum, & Preiss, 2011).

Electronic tools for working memory training, such as Cogmed (http://www.cogmed.com/), are highly effective. In particular, Cogmed is used in schools to enhance student’s learning performance (Drigas, Kokkalia, & Lytras, 2015). It consists of the Cogmed JM and Cogmed RM types for children and the Cogmed QM type for adults (Shipstead, Hicks & Engle, 2012) and includes visuo-spatial tests (e.g. “Asteroids”) and verbal memory tasks (e.g. “Input Module”) (Shipstead et al., 2012) that can be conducted in 25, 30 and 45 minute sessions over a period of five weeks (Aksayli, Sala & Gobet, 2019).

Video games also play a pivotal role in improving working memory capacity and performance (Karyotaki & Drigas, 2015). More specifically, video games positively impact visuo-spatial skills, which have been identified as a core part of working memory (Garcia et al., 2011); in fact, they allow individuals to exploit the potential of their visual working memory (Blacker & Curby, 2014). In particular, research conducted by Nouchi and Kawashima (2014) using a brain training video game called "Brain Age" (Nintendo Co. Limited, Kyoto, Japan), also known as Dr. Kawashima’s Brain Training (Himmelmeier, Nouchi, Saito, Burin, Wiltfang, & Kawashima, 2019) showed improved executive functions, enhanced working memory, and increased processing speed.
Furthermore, video games can be used effectively in school settings because they have a particular goal that children must try to reach, as well as a faster speed than traditional games. Children can understand instructions implicitly without reading them. Also, video games are independent from physical laws, capture players’ attention and continue to do so as the game builds a world with its own rules and regulations (Rosas, Nussbaum, Cumsille, Marianov, Correa, Flores, Lagos, Lopez, López, Rodríguez, & Salinas, 2003).

Additionally, serious games, which are defined as “a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives” (Zyda, 2005), can be used effectively for working memory training (Boendermaker, Gladwin, Peeters, Prins, & Wiers, 2018; Chaldogeridis & Tsiatsos, 2020).

5. Discussion and Conclusion

In this article, we presented the role of physical activity and ICT-based working memory interventions as a strategic issue for the improvement of students’ learning performance and thus their effective active presence at school and society. Because, nowadays, there is a great need for students not to be evaluated by the nation as an economic asset (Moyle, 2010) but to be considered as its valuable members, who can significantly contribute to its development.

Working memory refers to our ability to maintain and manipulate information, necessary for an action, for short periods of time in the order of seconds (Bhandari & Badre, 2016) and is closely associated with academic learning (Gathercole et al., 2006) as it plays a crucial role in the formation of the learning process (Drigas & Pappas, 2017). Working memory abilities in children and adolescents are benefited from physical activity, yielding higher improvements by chronic physical activity interventions (Haapala, 2012; Haverkamp et al., 2020). ICTs also significantly contribute to working memory enhancement and thus to the improvement of learning outcomes.

Additionally, working memory training plays a pivotal role in the development of metacognition, which is very important for the acquisition of knowledge (Drigas et al., 2017) and thus the improvement of the academic performance (Mitsea & Drigas, 2019) (Drigas & Karyotaki 2014). Furthermore, metacognition can be considered as the vehicle that could lead to consciousness (Mitsea et al., 2019), which is very important for the improvement of an individual’s quality of life.

To conclude, the catalytic role of working memory training in the development of consciousness, that is, the higher metacognitive processes of control, regulation and adaptation of the individual, according to the stratified model (8 Layer Model) of Drigas and Pappas (2017), could trigger educators and policy makers towards the ideal planning of working memory intervention programs adapted in school settings. Finally, taking into consideration the contribution of physical activity and ICTs to children’s and adolescents’ working memory abilities, physical activity and ICT-based working memory intervention programs that combine cognitive demands, motor-demanding activities and cardiovascular exercises could be incorporated into the school curriculum targeting the enhancement of school students’ working memory and the improvement of their learning performance.
References


[61] Lind, R. R.; Geertsen, S. S.; Ørntoft, C.; Madsen, M.; Larsen, M. N.; Dvorak, J.; Ritz, C.; Krstrup, P. Improved cognitive performance in preadolescent Danish children after the school-based physical activity programme “FIFA 11 for Health” for Europe–A


