


Acute Physical Activity for Motor and Academic Learning in Education-based Settings

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Abstract

Numerous studies have shown that physical activity (PA) provides significant benefits in several cognitive domains. For example, research suggests that even a single bout of PA has a positive impact on executive function, motor learning and academic performance. For this reason, many school settings have recently implemented acute PA-based strategies to improve their students' academic performance, such as active breaks or physically active learning. In this review, we recommend the use of acute physical activity interventions to improve the learning of motor-related academic skills in educational settings. We base our recommendations on studies that demonstrate the ability of acute exercise to facilitate skill acquisition during practice and to consolidate long-term declarative and motor memory, thereby promoting motor and academic learning. It is suggested that strategically placed acute practice strategies should be incorporated throughout the school day to promote both declarative and motor learning throughout the school day. In addition, we will consider the practical considerations for implementing this type of intervention in school settings. Finally, we will assess the limitations of the research to date and then discuss the next steps that need to be taken.

Keywords: Motor memory; Consolidation; Acute exercise; Learning; School

Resum

En els darrers anys s'ha produït un increment de la recerca que demostra beneficis de l'activitat física sobre diferents processos cognitius. Es destaquen els estudis que indiquen un impacte positiu d'una simple sessió d'exercici sobre el rendiment de les funcions executives, l'aprenentatge motor i el rendiment acadèmic. Arran de les darreres troballes, en diverses escoles s'està començant a implantar programes d'exercici agut al llarg de la jornada escolar per tal de millorar el rendiment acadèmic de l'alumnat. Alguns exemples són els descansos actius i les intervencions d'aprenentatge físicament actiu puntual. En aquesta línia, en la present revisió es proposa la utilització d'estratègies d'activitat física puntual a les escoles amb l'objectiu de millorar i potenciar l'aprenentatge del contingut motor acadèmic. La proposta es fonamenta en els estudis previs que han demostrat un

impacte positiu de l'exercici agut sobre els processos de consolidació a llarg termini dels aprenentatges motors. En aquest article repassarem les consideracions pràctiques que cal abordar en el disseny i implementació de les intervencions a l'escola, així com exposarem les limitacions de la recerca prèvia per discutir la prospectiva de futur del camp d'estudi.

Paraules clau: Memòria motriu; Consolidació; Exercici agut; Aprenentatge; Escola

Introduction

In recent years, there has been a growing body of research on the beneficial effects of physical activity (PA) on cognitive performance^{1,2}. Notably, these effects are not restricted to PA programmes designed as long-term interventions³. In fact, a single session of PA has been shown to positively influence performance on several cognitive tasks⁴⁻⁶. The acute priming of cognitive tasks by exercise can positively influence human performance for hours after exercise cessation. For example, Basso and colleagues demonstrated that exercise priming was maintained for up to 2 hours after the initial intervention in several tasks⁶. Conclusions drawn from these studies suggest that acute exercise may enhance cognitive task performance and learning. These findings appear to be highly applicable in educational settings. However, we should first ask why this is the case.

These studies are part of a body of research showing that PA can benefit different brain processes and mechanisms. To understand these beneficial effects, researchers have explored the biological mechanisms involved in the improvement of brain function after a bout of exercise. Recent evidence suggests that exercise-induced priming is a multifactorial mechanism involving neurotransmitter release⁷, increased expression of brain-derived neurotrophic factor (BDNF)⁸ and lactate accumulation⁹. PA also produces transient changes in brain activity that are beneficial for motor learning, such as in the prefrontal cortex (PFC)¹⁰, increased amplitudes in the attentional components (P3b, N450)¹¹, increases in corticospinal excitability (CSE) and intracortical inhibition (SICI) in the primary motor cortex (M1)^{12,13}. These functional changes acutely induced by PA may facilitate neural efficacy during specific cognitive tasks (such as the Stroop or Flanker task)^{14,15}, but

also during learning and consolidation processes¹⁶. For example, increases in lactate and BDNF enhance memory consolidation by facilitating long-term potentiation (LTP)^{17,18}, a critical molecular process involved in synapse formation and maintenance¹⁹⁻²¹.

Given these effects, numerous studies have analysed the acute influence of exercise on the acquisition and retention of declarative knowledge (e.g., lists of new words). They reported improved memory performance hours and days after the intervention²². These findings may have significant implications in educational settings, as acute PA may be an effective strategy for improving learning of curriculum content.

PA as a strategy to improve academic performance

Concern about children's inactivity during the school day has increased in recent years. Recent Global Matrix 4.0 reports have identified several negative indicators of regular physical activity in children that are of concern to policy-makers²³. In some countries, such as Denmark, mandatory time for physical activity in school has been increased²⁴. Programmes to teach academic content through physical activity or to introduce physical activity sessions in the classroom have been developed to reduce student inactivity. However, in addition to improving students' health, neuroscientific evidence has shown beneficial effects on cognitive processes that improve declarative learning and memory processes.

The above highlights how important PA can be in two ways. The first is because of the health benefits it can generate, and in this particular case, the cognitive health effects. Another approach is PA as a methodological tool to enhance learning and cognitive development in children. As a result, such research has enabled teachers to use different physical

activity-based strategies to improve both academic learning processes and, in turn, PA indicators.

Physical active learning (PAL) lessons, where curriculum content is delivered through games or PA practice^{25,26}, and active classroom breaks, where class is interrupted to engage in PA with or without academic content²⁷, are two examples of strategies that can be used both acutely and chronically²⁸. Studies of PAL and active breaks have reported improved academic outcomes and cognitive performance as a result of better attentional focus^{27,29}. These strategies are often integrated into teachers' practice^{30,31}, especially in those countries where a minimum amount of PA per day is compulsory in academic contexts (e.g. Denmark)³².

There are other educational strategies that have been explored recently but are less commonly used in academic settings. One example is acute exercise before or after content acquisition. Over the past decade, many studies have suggested that a bout of exercise immediately before or after the acquisition of factual content improves long-term retention³³⁻³⁷. For example, researchers compared the effects of performing an intense exercise session or resting immediately before learning a word list. They found that children who exercised recalled more words a day later.

These interventions focus on enhancing memory consolidation processes through a bout of PA^{16,22}. This may be key to achieving one of our ultimate goals as educators, which is for students to retain their learning for the long term so that they can use it at different points in their lives.

Nevertheless, when designing this type of intervention, teachers should consider several parameters that may modulate the benefits on memory, such as the intensity or timing of the exercise, in order to maximise the beneficial effects on memory (for a review, see Roig et al.³⁹). There is evidence that high-intensity exercise affects several mechanisms that support learning, such as BDNF. Timing is another important factor to consider. The timing of exercise in relation to the learning activity can influence its long-term consolidation. If exercise is performed before the learning task, it can improve short-term performance. However, exercise performed after encoding can help with consolidation and facilitate long-term memory, resulting in better performance on retention tests³⁹ (figure 1).

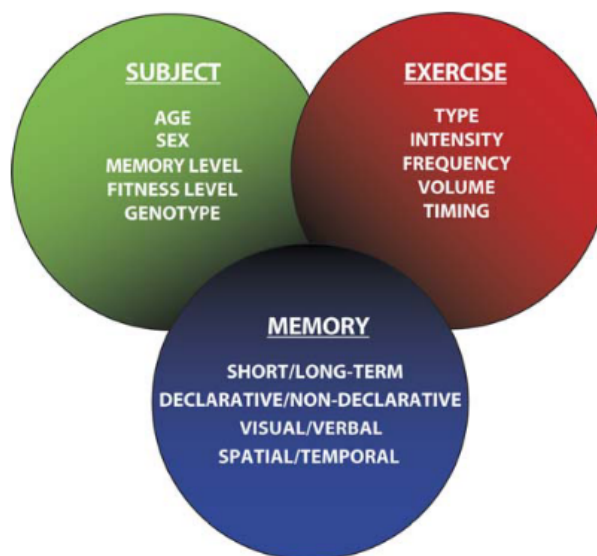


Figure 1. Factors that may moderate the effects of exercise on memory. Extracted from Roig et al.³⁹

Based on the previous findings, we suggest that acute physical activity (APA), which incorporates all of the previous strategies, could be used in educational settings to improve academic performance. Broadening our understanding of 'academic performance' is crucial, especially for children. It should not be limited to merely declarative learning. It is imperative to recognise "academic motor learning" - the acquisition of physical skills in an educational context - as an integral component of academic performance, in addition to conventional declarative knowledge-based learning, avoiding the classic mind-body dichotomy.

What about academic motor learning?

The development and learning of motor skills has become an important component of educational curricula worldwide, as motor skills are essential in everyday life and a strong predictor of an active lifestyle across the lifespan⁴⁰. PE teachers and sports coaches should consider the impact of physical activity (PA) on motor performance and learning when developing strategies for educational settings. This involves applying the findings of PA research to improve motor learning.

This suggestion is inspired by numerous stud-

ies that have reported the beneficial effects of a single bout of exercise on the retention of various motor skills^{41,42}. First, in 2012, Roig and colleagues conducted an experiment in which participants performed an intense bout of exercise immediately before or after practising a novel visuomotor tracking task⁴³. The results showed a significant improvement in motor retention one week after the intervention, but only in the exercise group. In the following years, numerous studies have demonstrated the benefits of acute exercise in producing long-term motor memory³⁷⁻³⁹ in different age groups, including young adults⁴⁴, older people⁴⁵ and children^{41,42,46}. This body of research has demonstrated positive effects of exercise on the consolidation of various motor tasks other than the visuomotor tracking learning task. For example, in a 2019 study conducted in Barcelona and Los Angeles, 71 children performed a visuomotor rotation adaptation task immediately following a 5-minute or 13-minute intense exercise session⁴². The results showed improved performance on the task for the children who engaged in either short or long term exercise, compared to those who rested. Therefore, a bout of exercise prior to motor skill training, regardless of its duration, may have a beneficial effect on long-term motor learning. As many schools may not have the time to incorporate physical activity extensively, reducing the likelihood of application may increase the opportunity for implementation.

From the above results we can highlight the economy and effectiveness of the intervention in improving the motor performance of the children in the task. An intensive 5-minute session before practice was sufficient to improve its long-term consolidation. This result, combined with the positive effects reported in other studies on children^{41,46}, may have implications for educational settings, as APA can be promoted as an effective strategy to improve curricular motor learning in the long term. This is the ultimate goal that teachers need to achieve with children as far as the motor domain is concerned. Therefore, we need to explore the potential of this strategy to see if it can be helpful to educators.

However, when analysing the literature on acute training and motor memory in order to summarise its application in practical contexts, we need to consider three main issues: practical considerations, practical implications and some limitations.

Practical considerations

In order to achieve a significant improvement in motor learning using APA, a thorough examination of its specific characteristics is essential. Extensive research has shown that the characteristics of APA are crucial in moderating its effects on motor memory⁴⁷. Three systematic reviews agreed on the importance of exercise characteristics in moderating the effects of acute exercise on motor learning and consolidation⁴⁷⁻⁴⁹. For example, high intensity appears to be critical in maximising the beneficial effects on motor memory⁵⁰. In addition to intensity, the timing of exercise is also important. It is widely accepted that exercise should be performed close to the motor task⁴⁹. Given that exercise-induced priming (increases in neurochemicals and brain activity) returns to baseline within minutes to hours after exercise⁵¹, temporal proximity must be considered. The timing of exercise refers not only to temporal proximity, but also to whether exercise is performed before or after the motor task. Some studies have suggested that practice before motor learning may improve performance by providing additional attentional and cognitive resources during practice. In contrast, post-practice practice could enhance memory consolidation and thus improve retention^{43,47}.

In addition, the type of exercise might also moderate these effects. Coordinatively demanding practice might have a greater effect on consolidation through complexity-dependent plasticity⁵². In addition to coordinative demands, Pesce and colleagues in 2009 found that team games were more effective at improving word retention than aerobic circuit training, probably due to the cognitive and coordinative demands of such exercise⁵³. However, some studies have failed to show differences between team games and simple exercises such as running, suggesting that the effects of exercise on motor memory may depend solely on physiological changes^{41,54}. If this is the case, any acute exercise could be useful in promoting motor learning processes, thus increasing the practical applications of APA interventions. However, muscle fatigue must be taken into account when designing the exercise according to the muscular demands of the motor task to be potentiated.

When analysing the duration of exercise, studies have found that as little as 5 minutes of exercise can effectively improve motor learning in children⁴².

These findings may increase the practical applicability of APA for motor learning, as some schools or teachers don't have much time to incorporate PA into children's daily routines (table 1).

Practical implications

Some schools have recently incorporated PA programmes into the academic schedule to make students more active^{55,56}. The aim of these interventions is not only to improve health habits, but also to improve academic performance. As mentioned above, active breaks and PAL could be examples. We propose to integrate APA into the regular school schedule as a systematic acute intervention to improve motor skill learning. APA could be incorporated immediately after physical education to improve long-term retention of classroom content. Alternatively, APA could be incorporated before class, especially when introducing a new motor skill. These APA interventions could be incorporated into transitions between subjects before the start of work time or just before dismissal.

Schools need to adapt their schedules to take full advantage of the many benefits of physical activity on both academic and motor performance. It is imperative that researchers broaden their focus beyond the laboratory and consider real-world scenarios to

fully understand the profound effects of exercise on student performance. Future research must prioritise the analysis of acute exercise in such scenarios to better inform policy and practice.

APA could also have an impact within physical education lessons. PE specialists can incorporate an acute bout of exercise into the PE session and make structural changes such as incorporating APA for motor learning into the regular schedule. A practical example could be the following: the main task of the session is a collaborative opposition passing game, where students have to use a new kind of passing skill to reach the goal, and the PE specialist places a five-minute exercise immediately after the task, where students have to run as fast as they can and touch the different lines of the pitch to solve a game. Some schools have recently introduced PA programmes during the academic schedule to make students more active^{55,56}. The aim of these interventions is not only to improve health habits, but also to improve academic performance. As mentioned above, active breaks and PAL could be examples. We propose to integrate APA into the regular school schedule as a systematic acute intervention to improve motor skill learning. APA could be incorporated immediately after physical education classes to improve long-term retention of classroom content. Alternatively, APA could be incorporated before class, especially when introducing a

Table 1. Moderators that educators should consider when designing APA for motor learning

PARAMETERS TO CONSIDER	
INTENSITY	Better results in long-term motor consolidation are observed when exercise is intense.
TIMING	Short time gap between exercise and motor learning task
	Prior exercise can enhance acquisition processes and follow-up exercise can strengthen longer-term consolidation processes.
DURATION	As long as it is energy-consuming, duration can be relatively short.
TYPE	Several types of exercise have been shown to be effective

new motor skill. These APA interventions could be incorporated into transitions between subjects before the start of work time or just before dismissal.

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Limitations and future directions

Although many studies have suggested that acute training is beneficial for motor learning when performed in temporal proximity to practice⁴⁷⁻⁴⁹, further research is needed from a practical perspective⁵⁷. This need for further research can be seen when analysing the motor tasks used in the literature to date. Most of the tasks have been simple motor tasks^{47,48}, which is a limitation for practical generalisations. As motor learning principles might differ between simple and more complex tasks⁵⁸, it is also possible that the motor consolidation process varies depending on the coordinative and cognitive demands of the task⁵⁹. For this reason, it is plausible that the effects of acute training in simple tasks may not be replicated in more challenging everyday or sports tasks^{60,61}.

The next few years will be crucial in expanding the practical applications of APA for motor learning. Future studies need to address more realistic motor tasks and analyse acute effects of practice in ecological contexts, such as school or sport. A first step was taken by Bonuzzi and colleagues, who demonstrated acute training effects on the retention of a

volleyball serve⁶². Future studies should also take into account the cognitive and coordinative demands of the tasks, which may moderate the effects on motor consolidation⁶¹.

Another important limitation is the population used in previous studies. Only four studies have analysed APA on motor learning in children^{41,42,46,63}. This characteristic should be reversed to increase the applicability of APA in academic and formative sports contexts. APA can potentially be an effective tool for improving motor learning in children. However, the paucity of research in this area involving children calls for caution in recommending APA for motor learning in academic contexts. Therefore, future research is encouraged to increase the transferability of findings to a wider range of educational contexts where motor learning is a developmental goal.

Conclusions

PA benefits cognitive function and academic performance (in motor and non-motor outcomes) by increasing the resources available to the brain uses during learning and consolidation processes. Educational contexts can use these findings to implement different acute interventions, such as PAL or active breaks, to facilitate learning processes and develop cognitive functions. In fact, several schools are already implementing these strategies. In addition, many national policies include them in their strategies, such as Denmark. However, in educational settings, most interventions have focused on declarative learning and ignored motor learning. In this review, we present the literature that reports the positive effects of acute exercise on motor learning. Based on these findings, we suggest that APA interventions should be implemented during physical education classes, depending on the motor content to be learned. We also suggest structural changes to the timetable, including APA before or after physical education, aimed at improving specific learning processes and cognitive skills, not only in physical education but also in other subjects. Furthermore, we must still be cautious about the applicability of these findings, as research is lacking when analysing APA in educational contexts or using more everyday or sports motor tasks. Future research should address these gaps and use a more ecological and transferable perspective in school and sport.

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