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Making the most of ourselves in the 21st century

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The Effect of Physical Activity on Mental Capital and Wellbeing

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Summary

The wide-ranging benefits of regular physical activity for physical health are well documented. In addition, many health researchers, clinicians and lay people also share the tacit assumption that exercise is vital for cognitive and mental health. However, until recently, evidence supporting that notion was limited. As research is gaining momentum, it becomes clear that physical activity indeed may enhance mental capital, mental wellbeing and brain health throughout life. This review explores that evidence, including current insights into the possible mechanisms that may mediate the effects of physical activity on mental capital and wellbeing. We end with a look at future work in this area, with some recommendations for optimising the research input.

1. Physical activity and mental capital

A growing body of observational research provides consistent evidence of a relationship between physical activity and mental capital, especially in elderly people. Longitudinal studies show not only that physical activity is associated with a reduced risk of age-related cognitive decline, but also that regular physical activity is linked to a lower risk of Alzheimer's disease (AD) and other forms of dementia.

Based on a review of studies with a follow-up period of at least five years, Rockwood and Middleton (2007) conclude that elderly people who exercise the most have a lower risk of cognitive impairment and dementia than those who exercise the least. For example, a large Canadian study of 9008 elderly men and women found that high levels of physical activity at baseline reduce the risk of cognitive impairment by 42% and halve the risk of developing AD (Laurin et al., 2001). Other prospective cohort studies support these conclusions (e.g. Larson et al., 2006; Yaffe et al., 2001).

Even regular physical activity in midlife may reduce the risk of dementia and AD later in life. A Finnish study with a 20-year follow-up period found that those who participate in regular (at least twice a week) leisure-time physical activity during midlife have 50% lower odds of dementia later in life compared with sedentary people (Rovio et al., 2005). Interestingly, this relation seems stronger in people with the highest genetic risk for developing AD (carriers of the APOE e4 gene). However, this finding has not been confirmed in all observational studies.

Despite robust results, these observational studies are not without difficulties. They use widely varying and often imprecise measures of physical activity (generally based on self-report), as well as differing methods to assess cognition or dementia, making it difficult to exactly capture the relationship between physical activity and cognition. Also, although care is taken to control for confounding factors, imperfect measurement of the confounders or unknown, uncontrolled confounders could still explain the association between exercise and cognition. Finally, to firm up conclusions about the direction of causality, intervention studies are needed in which the cognitive effects of a physical activity intervention are compared against the effects in an appropriate control group.

A small number of human randomised intervention trials have examined the effect of various exercise training regimens on cognitive function and brain structure and integrity. Most of these studies have been performed in elderly people, both normal adults and patients with early signs of AD. Overall, robust effects of training aimed at increasing cardio-respiratory fitness have been found on cognition and brain health (Colcombe and Kramer 2003; Heyn et al., 2004; with reported effect sizes of .60 and .57, respectively). Fitness training seems to broadly influence a wide range of cognitive functions. However, the largest effects are seen on quite specific cognitive processes, especially executive control tasks (e.g. planning, working memory, being able to focus in the face of distractions), all of which are most susceptible to ageing.

Interestingly, concomitant brain imaging data reveals that physical activity induces both structural changes in the brain and changes in patterns of functional activation. For example, a six-month aerobic training programme in healthy but sedentary elderly volunteers resulted in increased brain volume in both grey and white matter regions (Colcombe et al., 2006).

In contrast to the strong evidence for the beneficial influence of physical activity on cognitive function in the elderly, much less research is available on the relationship between physical activity and cognitive health during early childhood. Nevertheless, a meta-analysis of 44 studies did establish a positive association between physical activity and cognitive performance in school-age children (aged 4-18 years) in measurement categories such as perceptual skills, intelligence quotient, achievement, verbal tests, mathematic tests and developmental level/academic readiness (effect size =.32; Sibley and Etnier, 2003). Memory was found to be unrelated to physical activity behaviour.

Research on the relationship between physical activity and academic performance, however, is less consistent. Participation in physical activity has been found to either have a positive relationship with, or to be unrelated to, academic performance. For example, a US study indicated that achievement in tests of mathematics and reading was positively related to physical fitness scores in school-age children (California Department of Education, 2001). Other studies did not find such a relationship (e. g. Ahamed et al., 2007). Evaluating the available evidence, Hillman et al. (2008) conclude that "collectively these data indicate that, at the very least, time spent in physical activity programme does not hinder academic performance, and it might indeed improve performance" (p59). Comparable research on adolescents and younger adults is noticeable by its absence: in that age group there is little systematic work on the effects of physical activity on cognition (Hillman et al., 2008).

Although there seems to be consensus that physical activity probably improves cognition and brain function, not enough is known about the optimal parameters for achieving the cognitive benefits, namely: at what age is it important to be physically active; what type of exercise is needed; how intensively, for how long and how frequently. Notwithstanding the limited evidence, some tentative answers are emerging (Kramer and Erickson, 2007; Rockwood and Middleton 2007). Most data suggests that there is a larger benefit for aerobic exercise over a non-aerobic training regimen. The level of cardio-respiratory fitness achieved may thus be an important modifying factor, although in elderly people, strength training also leads to positive outcomes (Colcombe and Kramer, 2003).

Most studies find a dose-response relationship for the protective effects of exercise on cognitive function, with greater amounts of exercise resulting in better protection. At the same time, the good news is that the greatest incremental benefit seems to be associated with the transition from no exercise at all to a low level of exercise. It is generally recommended that exercise should be of moderate intensity, in sessions ideally longer than 30 minutes, at least three times a week. Physical activity is likely to be beneficial for brain function at all ages whereby exercise early in life and in midlife may also preserve cognitive ability in later life. On the other hand, it is never too late to start, as proven by the positive influence of exercise on cognitive function in sedentary elderly people.

How gender moderates the fitness effect is unclear. In a meta-analysis, studies that included more than 50% women showed larger cognitive benefits from fitness training than those that enrolled mostly men. The gender gap needs further investigation but may be due to an interactive effect of fitness with the hormone oestrogen in female participants (Kramer and Erickson, 2007).

2. Mechanisms mediating the effect of physical activity on mental capital

In vitro and animal studies have begun to reveal the cellular and molecular mechanisms by which physical activity may influence cognition and brain structure and function. Many of the cardiovascular risk factors (e.g. hypertension, dyslipidaemia and Type 2 diabetes) are associated with an increase in the risk of cognitive impairment and dementia (Grodstein, 2007). A common feature of these conditions is systemic inflammation which can exacerbate CNS inflammation and also correlates with cognitive decline. Physical activity not only lowers peripheral cardiovascular risk factors but regular physical exercise also suppresses chronic inflammation, which may indirectly improve brain health (Cotman et al., 2007b; Kasapis and Thompson, 2005; Pedersen et al., 2007).

Using animal models, a number of central mechanisms have been studied that may explain the relationship between physical activity and cognitive function (see Cotman and Berchtold, 2007a, for an overview). Central effects of exercise on the structure and function of the brain have been most studied in the hippocampus, a key region for learning. Exercise has direct vascular benefits in the brain by maintaining cerebral blood perfusion and promoting the growth of vasculature (Swain et al., 2003). Exercise also facilitates synaptic plasticity and particularly enhances long-term potentiation – the synaptic analogue of learning (Vaynman and Gomez-Pinella, 2005). Exercise promotes neuronal viability and also increases hippocampal neurogenesis in adults, the formation of new neurons in the dentate gyrus of the hippocampus (Van Praag et al., 2005). Finally, in animal models, voluntary running reduces the load of amyloid-β, one of the hallmarks of AD neuropathology (e. g. Adlard, et al., 2005).

A common signalling or mechanistic pathway may underlie all of these effects on the central nervous system. There is growing evidence that neurotrophins, particularly brain-derived neurotrophic factor (BDNF), are key mediators of exercise-driven brain responses. As Cotman and colleagues argue (2007a; 2007b), these neurotrophins, a family of protein that promotes the survival of neurons, may represent a hub through which exercise can drive neuronal plasticity, improve cognition and protect the brain against insult. BDNF is an important, primary signalling molecule which, in turn, depends on the expression of insulin-like growth factor-1 (IGF-1) and vascular endothelial growth factor (VEGF). All these growth factors may work in concert to produce the complementary functional effects of exercise in the brain.

3. Physical activity and mental wellbeing

Across all age groups, regular physical activity is cross-sectionally associated with a greater sense of wellbeing and lower depression and anxiety (Biddle and Ekkekakis, 2005; Teychenne et al., 2008). However, cross-sectional data cannot shed light on the direction of causality between physical activity and mental wellbeing. Regular physical activity may indeed enhance wellbeing but, equally, a strong sense of wellbeing may be a prerequisite for adhering to an habitual exercise programme. Or the two factors may be simply correlated. Some longitudinal studies indicate that physical activity levels at baseline are predictive of later depressive symptoms. Although this data provides some support for the view that regular physical activity may protect against the development of depressive symptoms, experimental studies are needed to tease out the causal relations.

A number of randomised controlled trials have examined the use of exercise training as a treatment for depression. However, methodological weaknesses (inappropriate control groups, issues around allocation concealment and blinding, representative sample etc) throw some doubt over some of these studies (Lawlor and Hopker, 2001; Steptoe, 2006).

Nevertheless, there now are a growing number of well-designed experimental studies suggesting that physical activity has beneficial effects on clinical depression and depressive symptoms in otherwise healthy adults. For example, Blumental and colleagues (1999) found that after a 10-month follow-up period, elderly participants with major depressive disorder who participated in a 16-week, structured exercise intervention had a lower rate of depression than those in a medication or a combined-treatment group. In the Depression Outcomes Study of Exercise, reductions in depressive symptoms (measured by the Hamilton Rating Scale for Depression) were found to be related to intensity of exercise, with greater reductions in depression with higher-intensity exercise (Dunn et al., 2005). Similarly, there is promising preliminary evidence for the use of exercise in the treatment of anxiety in adults (Broman-Fulks and Storey, 2008). In children and adolescents, the evidence for the role of exercise in the treatment of depression and anxiety is less clear: research data are too sparse to allow for valid conclusions to be drawn (Larun et al., 2006).

Outside of the clinical realm, evidence is available, especially in elderly people, that physical activity impacts on psychological wellbeing in a broad sense, with effects not just on negative emotions but also on global wellbeing, positive affect, view of self and self-efficacy (Netz et al., 2005).

Similar questions as before about type, frequency and intensity of physical activity also need clarification in the context of mental wellbeing. In one analysis, improvements in physical fitness status were associated with greater benefits for wellbeing (Netz et al., 2005). Moderate activity seems to be most beneficial, with sessions lasting more than 30 minutes, a few times a week. However, benefits were also seen in studies prescribing relatively low intensity and duration of physical activity (Teychenne et al., 2008). Low impact physical activity such as stretching, toning and yoga may similarly be effective in reducing depressive symptoms and increasing psychological wellbeing (Frye et al., 2007; Shapiro et al., 2007).

4. Mechanisms underlying the link between physical activity and mental wellbeing

Various psychological and physiological processes and mechanisms have been invoked to explain the association between physical activity and wellbeing. Steptoe (1992) discusses a range of psychological processes put forward as mediators of the relationship between physical activity and mental wellbeing. For example, exercise provides a 'mastery experience' that increases self-efficacy and promotes one's perceived ability to cope. This may positively impact on mood and help to counteract depression. Exercise also distracts from negative emotion and thoughts, prevents rumination or alters the accessibility or intensity of ruminations, worries and anxiety. Another explanation is that part of the positive effect of exercise may be due to the modification of emotional action tendencies, in that exercise involves activity that is inconsistent with natural action tendencies associated with depression (withdrawal, passivity). Finally, improvements in mental health following exercise could also, at least partly, be related to the mutual support and social relationships provided when participating in physical activity with others.

Some of the cellular and molecular mechanisms put forward to explain the relationship between physical activity and mental capital may also account for the link between exercise and mental wellbeing (Cotman et al., 2007b). For example, depression is associated with overactive inflammatory responses. As mentioned above, physical activity mitigates peripheral inflammation and improves the overall immune condition of the brain, which may reduce depressive symptoms. Stress and depression also lead to decreased expression of neurotrophic factors and reduced levels of neurogenesis (Duman, 2004). As described above, exercise precisely increases the expression of neurotrophic factors, BDNF in particular, and increases neurogenesis.

The therapeutic effects of physical activity may also be accounted for by changes in central neurotransmitter function. The central monoamine theory states that exercise corrects dysregulation of monoamines such as serotonin and norepinephrine, believed to contribute to depression (Salmon, 2001). Exercise may also activate endorphin secretion which reduces pain and produces a euphoric sensation (Paluska and Schwenk, 2000).

At present, there is no consensus about the relative importance of these mechanisms. In all likelihood, a combination of psychological processes and biological mechanisms underlie the favourable effects of physical activity on mental wellbeing.

5. Future developments

Although considerable progress has been made, this research area still has some way to go. Both the evidence base and our understanding of underlying mechanisms need further building. More empirical studies are required to elucidate the relationship between physical activity and mental capital and wellbeing across the human lifespan.

Particularly striking is the paucity of research on the effect of physical activity on cognitive function, academic performance and mental health in children and adolescents. Also, research on the influence of physical activity on positive wellbeing should be stimulated.

In general, across the ages, too little is known about moderating variables: what variety, intensity, frequency and duration of physical activity will have a beneficial impact on brain health?

Also, even though exercise interventions are growing more sophisticated and sound, methodological issues, such as control for confounding factors and the use of appropriate control groups, still need to be better addressed.

A dedicated and well-funded research programme could help to direct and accelerate developments in this research field. An integrated approach is needed with funding made available for observational studies and for large, randomised controlled intervention trials, as well as for more mechanistic studies using appropriate animal models to uncover the mediators of the relationship between physical activity and brain health.

In the future, research into the links between physical activity and mental capital and wellbeing will benefit from (and be partly spurred on by) technological developments. Physical activity is a complex, multidimensional behaviour that is not fully captured by self-report measures. Objective monitoring of physical activity is therefore preferable (Wareham and Rennie, 1998). The development of more sophisticated physical activity monitors that will enable researchers to assess intensity, duration and the type of activity in a reliable manner will significantly contribute to the advancement of the research. Equally, further advances in modern neuroimaging techniques will enable scientists to more accurately study the structural, physiological and functional changes in the brain associated with physical activity.

Finally, given the progress in genetic profiling, the moderating influence of genotypic variations on the size of cognitive and brain effects resulting from physical activity can now be investigated. This opens up the possibility that, in the far future, physical activity interventions could perhaps be custom-tailored on the basis of the genomic profiles of individuals.

In the immediate term, however, more efforts need to be made to translate research findings into best practices or evidence-based recommendations and to close the gap between research and clinical and community practice. In clinical practice, adjunctive exercise interventions could be offered for treating depression and anxiety, and exercise therapy could have a place in the prevention and treatment of cognitive decline.

Crucially, however, we still do not fully understand how to best design effective exercise interventions aimed at cognitive and mental health that benefit everyone, especially the hard-to-reach population. There is an opportunity here to not only target physical activity behaviour at an individual level but to also focus on collective determinants of such behaviour. Through environmental changes (e.g. better infrastructure) and deliberate policy intent (e.g. stronger emphasis on physical activity in the educational curriculum), increases in physical activity can perhaps be stimulated at a population level.

Finally, physical activity should not be considered and targeted in isolation from other lifestyle behaviours (such as diet, sleep, socialising) that also influence mental capital and wellbeing. A holistic approach to encourage the adoption of a healthier lifestyle across the board will have an amplifying effect on the cognitive and emotional health of the population.

6. Conclusion

In addition to the broad physical health benefits of exercise, a growing evidence base supports the beneficial effects of regular physical activity for cognitive and mental health. The adoption of an active lifestyle may contribute to optimal mental capital and wellbeing throughout life, which provides yet another reason to encourage physical activity across the lifespan.

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