# Physical Activity for Cognitive and Mental Health in Youth: A Systematic Review of Mechanisms

David Lubans, PhD,[a] Justin Richards, PhD,[b] Charles Hillman, PhD,[c] Guy Faulkner, PhD,[d] Mark Beauchamp, PhD,[d] Michael Nilsson, PhD,[e] Paul Kelly, PhD,[f] Jordan Smith, PhD,[a] Lauren Raine, BSc,[c] Stuart Biddle, PhD[g]

abstract

**CONTEXT:** Physical activity can improve cognitive and mental health, but the underlying mechanisms have not been established.

**OBJECTIVE:** To present a conceptual model explaining the mechanisms for the effect of physical activity on cognitive and mental health in young people and to conduct a systematic review of the evidence.

**DATA SOURCES:** Six electronic databases (PubMed, PsycINFO, SCOPUS, Ovid Medline, SportDiscus, and Embase) were used.

**STUDY SELECTION:** School-, home-, or community-based physical activity intervention or laboratory-based exercise interventions were assessed. Studies were eligible if they reported statistical analyses of changes in the following: (1) cognition or mental health; and (2) neurobiological, psychosocial, and behavioral mechanisms.

**DATA EXTRACTION:** Data relating to methods, assessment period, participant characteristics, intervention type, setting, and facilitator/delivery were extracted.

**RESULTS:** Twenty-five articles reporting results from 22 studies were included. Mechanisms studied were neurobiological (6 studies), psychosocial (18 studies), and behavioral (2 studies). Significant changes in at least 1 potential neurobiological mechanism were reported in 5 studies, and significant effects for at least 1 cognitive outcome were also found in 5 studies. One of 2 studies reported a significant effect for self-regulation, but neither study reported a significant impact on mental health.

**LIMITATIONS:** Small number of studies and high levels of study heterogeneity.

**CONCLUSIONS:** The strongest evidence was found for improvements in physical self-perceptions, which accompanied enhanced self-esteem in the majority of studies measuring these outcomes. Few studies examined neurobiological and behavioral mechanisms, and we were unable to draw conclusions regarding their role in enhancing cognitive and mental health.

[a]*Priority Research Centre for Physical Activity and Nutrition, School of Education, University of Newcastle, Callaghan Campus, Australia;* [b]*Prevention Research Collaboration, School of Public Health and Charles Perkins Centre, University of Sydney, Australia;* [c]*Department of Kinesiology and Community Health, University of Illinois, Illinois;* [d]*School of Kinesiology, University of British Columbia, Vancouver, British Columbia, Canada;* [e]*Hunter Medical Research Institute, University of Newcastle, Callaghan Campus, Australia;* [f]*Physical Activity for Health Research Centre, University of Edinburgh, United Kingdom;* [g]*Institute of Sport, Exercise & Active Living, Victoria University, Australia*

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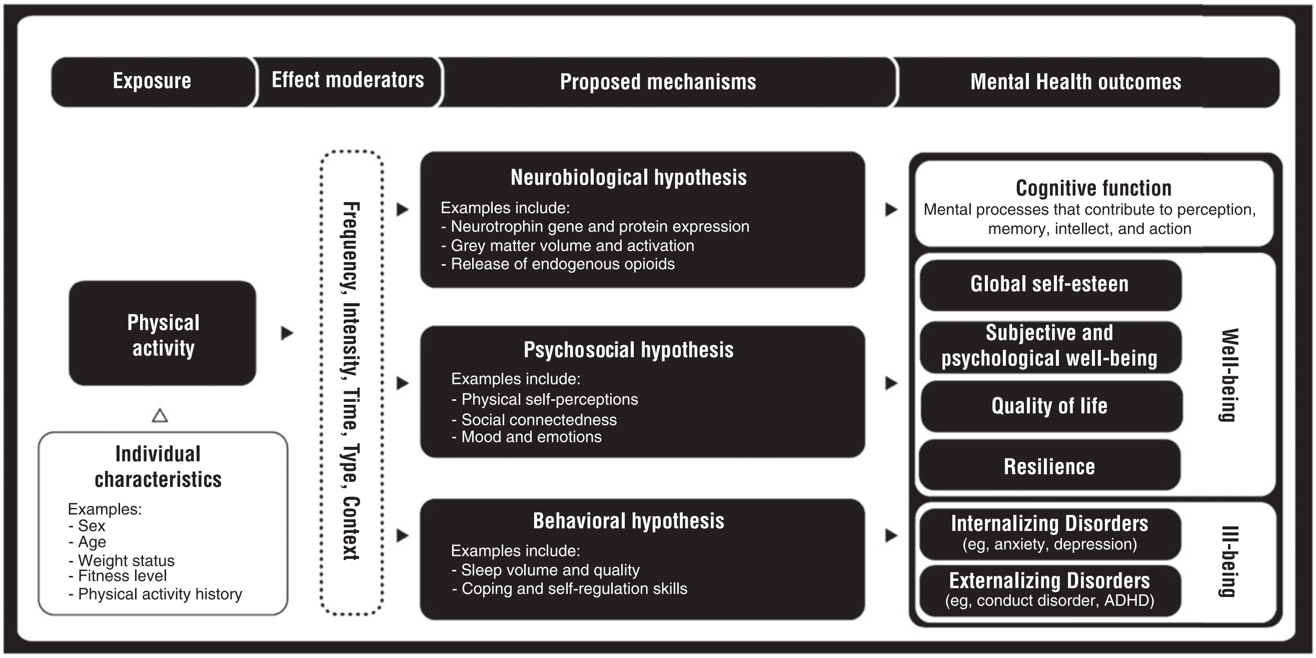


**FIGURE 1**
Conceptual model for the effects of physical activity on mental health outcomes in children and adolescents. ADHD, attention-deficit/hyperactivity disorder.

The World Health Organization defines mental health as a state of well-being and effective functioning in which an individual realizes his or her own abilities, is resilient to the stresses of life, and is able to make a positive contribution to his or her community.[1] Cognitive function, defined as mental processes that contribute to perception, memory, intellect, and action, provides a core foundation upon which mental health (both well-being and ill-being) is established.[2] There is conceptual overlap among common indicators of well-being, which commonly include constructs of global self-esteem, subjective well-being, quality of life, and psychological resilience. For the purpose of the current review, the term ill-being is used to represent preclinical psychological states and clinically diagnosed mental health disorders (Supplemental Table 4 provides definitions for these variables).

Childhood and adolescence represents a period of rapid growth and development characterized by neuronal plasticity,[3] formulation of self-concept,[4] and the establishment of behavioral patterns that may enhance or diminish mental health.[5] This period may be critical for improving mental health, and the delivery of physical activity interventions might be 1 way of achieving such improvements.[6] Although a bidirectional relationship between physical activity and mental health could exist, experimental studies conducted with youth have shown that increasing physical activity has small but positive effects on a range of cognitive and mental health outcomes.[6–9] Despite an increasing number of experimental studies reporting the cognitive and mental health benefits of participating in physical activity, the underlying mechanisms responsible for the positive effects have not been established.[10–12]

The ability to explain how and under what conditions mental health changes occur may facilitate the delivery of successful interventions. Thus, the goals of the current article were as follows: (1) to present a conceptual model for explaining the effects of physical activity on cognitive and mental health outcomes in young people; and (2) to conduct a systematic review of physical activity interventions that have examined the impact on mental health outcomes and potential mechanisms in child and adolescent populations. The conceptual model includes 3 broad potential mechanisms (neurobiological, psychosocial, and behavioral), which are summarized in Fig 1 and explained in more detail in the following sections.

## ELEMENTS OF CONCEPTUAL MODEL

### Neurobiological Mechanisms

The neurobiological mechanism hypothesis proposes that participation in physical activity enhances cognition and mental health via changes in the structural and functional composition of the brain.[13,14] In a review, Voss et al[15] identified 3 broad categories of neurobiological mechanisms responsible for cognitive functioning, involving changes in the central nervous system: (1) cells, molecules, and circuits that, with current scientific techniques, are only detectable in animal studies (eg, neurogenesis); (2) biomarkers (eg, gray matter volume, cerebral blood volume, flow); and (3) peripheral biomarkers (eg, circulating growth factors, inflammatory markers) that can be observed in humans.

Neuroimaging techniques (eg, MRI, functional MRI [fMRI], and event-related brain potentials) have been used to identify structural and functional mechanisms that may explain the relationship between physical activity, cardiorespiratory fitness, and cognition.[16] Such techniques do not provide a direct measure of mechanism change; instead, they represent the outcome of some other mechanistic change in the brain that is not directly measurable in human subjects. The animal literature has identified a number of mechanistic examples (eg, changes in brain-derived neurotrophic factor). Research in rodents has indicated that running increases cell proliferation, survival, and differentiation.[17] Furthermore, exercise stimulates the growth of new capillaries, which are critical for the transport of nutrients to neurons.[18] Brain-derived neurotrophic factor, insulin-like growth factor 1, and vascular endothelial growth factor are neurochemicals that increase with exercise and facilitate the downstream effects of cardiorespiratory exercise on brain structure, function, and cognition.[19] These neurochemicals are highly concentrated within the hippocampus, as well as various other brain regions.[20] Evidence also exists for the benefits of cardiorespiratory fitness on the structure of the brain's cortical (eg, frontal lobes, anterior cingulate) and subcortical (eg, hippocampus, basal ganglia) regions.[21,22]

There may also be neurobiological explanations for the effects of physical activity on well-being and ill-being, through the release of endogenous opioids and their interaction with other neurotransmitter systems.[14] Participation in physical activity is believed to lead to the release of endorphins, which can ease pain and produce a feeling of euphoria.[14] However, there is little empirical evidence to support this assertion in adults[14] or children.[23] It is unknown if the short-term pleasure that individuals experience during physical activity is due to endorphins and to what extent this action contributes to improved mental health in young people over time. The "feel good" effect of activity may be due to changes in 1 or more brain monoamines, with the strongest evidence available for dopamine, noradrenaline, and serotonin.[13]

### Psychosocial Mechanisms

Drawing upon both hedonic[24] and eudemonic[25,26] perspectives (Supplemental Table 4), physical activity has the potential to improve well-being via a range of psychosocial mechanisms. Several theoretical frameworks propose that well-being is achieved by satisfying basic psychological needs for social connectedness, autonomy, self-acceptance, environmental mastery, and purpose in life.[27,28] Our psychosocial mechanism hypothesis recognizes that physical activity provides an opportunity for social interaction (relatedness), mastery in the physical domain (self-efficacy and perceived competence), improvements in appearance self-perceptions (body image), and independence (autonomy). In addition, physical activity can facilitate interaction with the natural environment[29]and potentially improve mood, which may affect wider affective states and other indicators of well-being.

Consistent with existing theoretical models,[30,31] participation in physical activity may lead to improved task self-efficacy (ie, one's confidence in their ability to perform specific activities), which generalizes first to broader physical self-concept and then to global self-esteem. However, physical activity may also have a negative impact on mental health outcomes among children and adolescents in certain contexts and circumstances.[32,33] For example, poorly designed and delivered physical education lessons may thwart students' needs satisfaction and lead to decreases in perceived competence and global self-esteem. Similarly, participation in physical activity may also influence physical self-perceptions within the appearance subdomain (eg, perceived attractiveness, body image).[34]

Short-term experimental studies have shown promising effects on self-reported well-being immediately after exercise in natural environments, which are not seen after the same exercise indoors.[29] These findings are grounded in the theory that humans are biologically predisposed to be attracted to nature and have spent the majority of their evolutionary history in natural environments.[35] Among adults, connectedness to nature has been found to be positively associated with mental health outcomes.[36] In addition, the restorative properties of natural environments may explain why participation in physical activity in natural environments has mental health benefits.[37,38]

### Behavioral Mechanisms

The behavioral mechanism hypothesis proposes that changes in mental health outcomes resulting from physical activity are mediated by changes in relevant and associated behaviors. In particular, participation in physical activity may improve sleep duration, sleep efficiency,[39,40] sleep onset latency,[41] and reduce sleepiness.[42] In addition, participation in physical activity programs may also influence self-regulation and coping skills that have subsequent implications for mental health.

Participation in physical activity is recommended for the management of adolescents experiencing sleepiness and fatigue.[43] Although the majority of studies reporting a relationship between sleep-related outcomes and physical activity have been cross-sectional, it is plausible to suggest that increasing energy expenditure through activity may influence sleep patterns, which may, in turn, improve mental health outcomes. Of note, a systematic review and meta-analysis concluded that insufficient sleep was associated with deficits in higher order and complex cognitive functions and with an increase in behavioral problems in children.[44]

Participation in physical activity provides an opportunity for the development of self-regulation and coping skills that may influence mental health. For example, yoga is a holistic system of multiple mind–body practices for mental and physical health that includes relaxation practices, cultivation of awareness/mindfulness, and meditation[45] that help develop coping skills. A systematic review concluded that yoga may have utility for treating anxiety or anxiety-related disorders in child and adolescent populations.[46] The development of self-regulation and coping skills promoted in recreational activities such as yoga and martial arts may explain the positive effects of these activities on mental health.[46,47]

### Summary of Conceptual Model

Numerous reviews have demonstrated the positive impact of physical activity on cognitive and mental health outcomes in child and adolescent populations,[6,8,9] and a range of potential mechanisms have been described.[10–12] These factors are summarized in the conceptual model in Fig 1. To our knowledge, the current article is the first systematic review of the mechanisms responsible for the effects of physical activity on cognitive and mental health in young people.

## METHODS

The conduct and reporting of this review adhered to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-analysis statement.[48]

### Study Eligibility Criteria

1. Types of participants: Participants were school-aged (ie, 5–18 years) at baseline. Studies targeting populations with learning difficulties, cognitive deficits, and developmental disorders were not included.

2. Types of interventions: Any school-, home-, or community-based physical activity intervention or laboratory-based exercise intervention. Obesity prevention or treatment interventions that included a dietary component were not eligible for inclusion.

3. Types of mental health outcome measures: Studies were included if they reported statistical analyses of changes in cognitive function or indicators of global well-being or ill-being.

4. Types of potential mediators: Studies were included if they reported statistical analyses of changes in potential neurobiological, psychosocial, and behavioral mechanisms.

5. Types of study designs: Study designs included experimental or quasi-experimental (ie, nonrandom allocation of participants to groups) studies of at least 1 week in duration.

### Information Sources and Search Strategy

Six electronic databases (PubMed, PsycINFO, SCOPUS, Ovid Medline, SportDiscus, and Embase) were searched from the year of their inception up to July 2015 (Supplemental Table 5). An additional search of recently published systematic reviews examining the effects of physical activity on mental health outcomes was conducted, and the reference lists of all retrieved studies were reviewed.

### Data Extraction

Study data relating to methodology, assessment period, participant characteristics, intervention setting, intervention facilitator/delivery, and intervention description were extracted and are reported in Supplemental Table 6.

### Risk of Bias Assessment

Risk of bias was assessed by using the Physiotherapy Evidence Database scale.[49] This scale consists of 11 separate items representing different sources of potential bias in scientific research (Supplemental Table 7).

## RESULTS

### Overview of Studies

Fig 2 displays the flow of studies through the review process. After the exclusion of duplicates, the initial database search yielded 7118 potentially relevant citations, of which 97 were retained for full-text review (Supplemental Table 6). From this phase, 18 articles satisfied the inclusion criteria and an additional 7 relevant articles were identified from the reference lists of included articles and hand-searches. The studies were conducted in North America (12 in the United States and 2 in Canada), Europe (1 each in the United Kingdom, Spain, Switzerland, Sweden, France, Norway, and Portugal), Oceania (3 in Australia), and Asia (1 in China). In total, 20 studies used a randomized controlled trial (RCT) design (5 cluster RCTs), and the remaining 5 studies used a nonrandomized controlled design. The sample size for included studies ranged from 18 to 1273.

### Risk of Bias for Included Studies

Detailed information on the risk of bias for the included studies is presented in Supplemental Table 7. In total, 12 (48%) studies satisfied fewer than one-half of the risk of bias criteria, and 6 (24%) studies satisfied two-thirds or more. The most consistently satisfied criteria were items 1 ("eligibility criteria" [80% of studies]) and 10 ("between-group comparisons" [100% of studies]); the most poorly satisfied were items 5 ("blinded subjects" [no studies]) and 6 ("blinded intervention facilitators" [no studies]).

### Neurobiological Mechanisms

Six articles (3 unique studies) tested the effects of physical activity intervention on potential neurobiological mechanisms and cognitive outcomes (Table 1), all of which were RCTs.[7,22,50–53] The sample size for these studies ranged from 18 to 221, and studies exclusively targeted children (age range, 7–11 years). A variety of potential neurobiological mechanisms were evaluated, but there was little overlap between studies. For example, included studies evaluated characteristics of brain structure and functioning across a variety of brain regions using MRI, fMRI, and electroencephalography. The specific outcomes assessed within these studies also varied but were all related to aspects of cognitive performance. Significant changes in at least 1 potential mechanism were reported in 5 (83%) studies, and effects for at least 1 cognitive outcome were also found in 5 studies. Four studies examined associations between changes in potential mechanisms and changes in mental health outcomes, and significant associations were found in 2 of these studies.

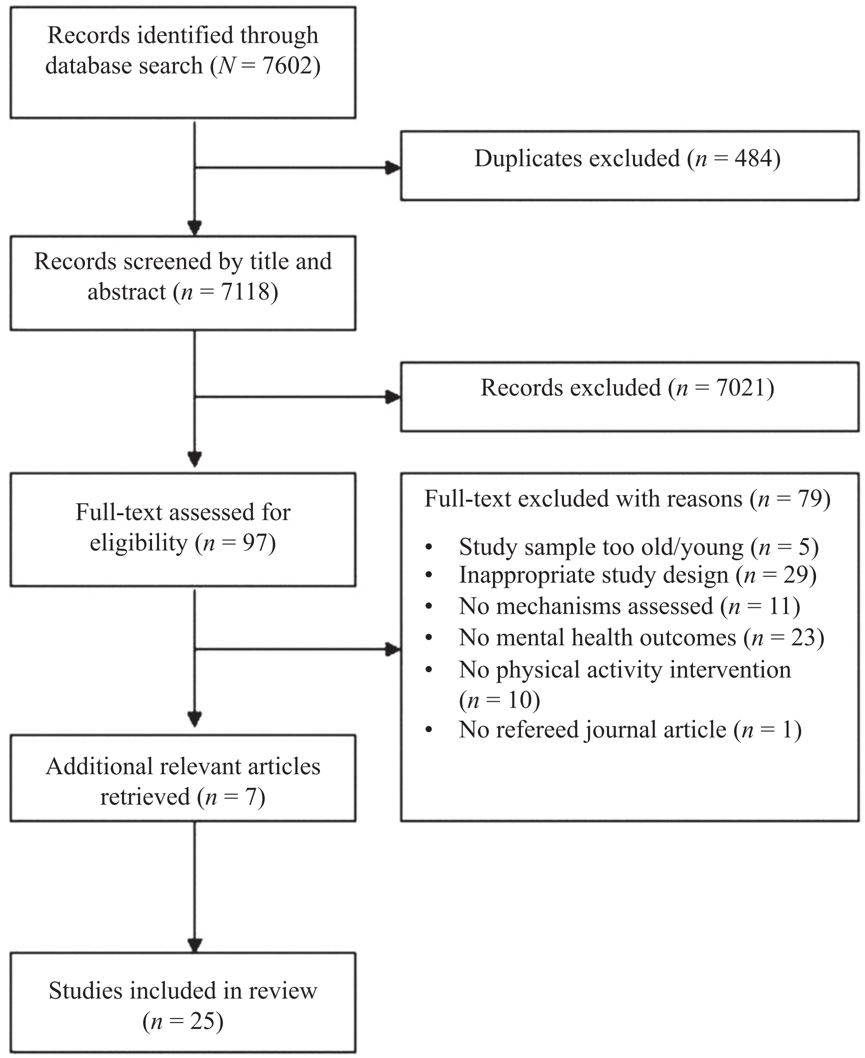


**FIGURE 2**
Flow of studies through the review process.

### Psychosocial Mechanisms

Eighteen studies examined the effects of physical activity interventions on psychosocial mechanisms and mental health outcomes[54–71]; 13 of these were RCTs, and 5 were quasi-experimental trials (Table 2). Study sample sizes ranged from 20 to 1273, and studies targeted both children and adolescents. The most commonly evaluated psychosocial mechanisms were physical self-concept and physical self-perceptions (encompassing competence, appearance, and fitness subdomains). A range of mental health outcomes were evaluated, with studies reporting the effects of the interventions on self-esteem, depression, quality of life, psychological well-being, vitality, general self-efficacy, and positive/negative affect. Of the 18 studies, 12 (67%) reported a significant intervention effect for at least 1 potential mechanism, and 11 (61%) reported a significant intervention effect for at least 1 mental health outcome.

### Behavioral Mechanisms

Only 2 studies[56,72] evaluated the effects of interventions on behavioral

**TABLE 1** Physical Activity Intervention Effects on Neurobiological Mechanisms and Cognitive Outcomes

| Study | Mechanism | Physical Activity Effect on Mechanism | Changes in Mechanism and Cognitive Outcomes[a] | Physical Activity Effect on Cognitive Outcomes |
|---|---|---|---|---|
| Chaddock-Heyman et al (2013)[50] | Right anterior prefrontal cortex | — | + | Neutral reaction time (–)[b] |
| | Anterior cingulate cortex | NS | + | Incongruent reaction time (–)[b] |
| | | | | Incongruent accuracy (+ trend) |
| | | | | Neutral accuracy (+) |
| | | | | No-go accuracy (NS) |
| Davis et al (2011)[22] | Bilateral prefrontal cortex | + | NR | Planning (+) |
| | Bilateral posterior parietal cortex | — | | Attention (NS) |
| | | | | Simultaneous (NS) |
| | | | | Successive (NS) |
| | | | | Broad math (+) |
| | | | | Broad reading (NS) |
| Kamijo et al (2011)[51] | Initial contingent negative variation | + | + | Working memory (+) |
| | Terminal contingent negative variation | NS | | |
| Krafft et al (2014)[52] | Antisaccade imaging results | | | |
| | Bilateral precentral gyrus | — | All NS[c] | Response inhibition (NS) (antisaccade task) |
| | Medial frontal gyrus | — | | |
| | Paracentral lobule | — | | |
| | Postcentral gyrus | — | | |
| | Superior parietal lobule | — | | |
| | Inferior parietal lobule | — | | |
| | Anterior cingulate cortex | — | | |
| | Right inferior frontal gyrus | — | | |
| | Insula and left precuneus | — | | |
| | | | | Response selection (NS) |
| | Flanker imaging results | | All NS | (flanker task) |
| | Left medial frontal gyrus | + | | |
| | Superior frontal gyrus | + | | |
| | Middle frontal gyrus | + | | |
| | Superior temporal gyrus | + | | |
| | Cingulate gyrus and insula | + | | |
| Krafft et al (2014)[53] | White matter structure | NS | — | Cognitive function composite (NS) |
| | | | | Planning (NS) |
| | | | | Attention (NS) |
| | | | | Simultaneous processing (NS) |
| | | | | Successive processing (NS) |
| | | | | Global executive function (–)[b] |
| | | | | Metacognition index (–)[b] |
| Hillman et al (2014)[7] | Neuroelectric index of attention (P3 amplitude); Processing speed (P3 latency) | + (incongruent and heterogeneous trials only) | +[d] | Attentional inhibition |
| | | | | Response accuracy (+) |
| | | | | Reaction time (NS) |
| | | | | Cognitive flexibility |
| | | | | Response accuracy (+)[e] |
| | | | | Reaction time (NS) |

+, significant increase or association; —, significant decrease or association; NS, nonsignificant ($P \geq .05$) for group-by-time interaction; NR, not reported.
[a] The relationship between changes in hypothesized mechanism and changes in one or more cognitive outcomes.
[b] Decrease in scores reflects better performance.
[c] Decrease in activation in the right superior parietal lobule was correlated with faster error latencies.
[d] Intervention session attendance was correlated with the magnitude of change in P3 amplitude and latency, as well as response accuracy.
[e] Significant for heterogeneous.

mechanisms, and of these, only changes in self-regulation skills were assessed (eg, self-control) (Table 3). One of the 2 studies[72] reported significant intervention effects for self-regulation, but neither study reported a significant impact on mental health.

## DISCUSSION

Despite consensus that physical activity plays an important role in promoting optimal cognitive and mental health in young people,[73] little is known regarding the mechanisms by which this effect works. Through our systematic review, we mapped a range of potential mechanisms

**TABLE 2** Physical Activity Intervention Effects on Psychosocial Mechanisms and Mental Health Outcomes

| Study | Potential Mechanisms | Physical Activity Effect on Mechanism | Changes in Mechanism and Changes in Mental Health | Physical Activity Effects on Mental Health Outcomes |
|---|---|---|---|---|
| Annesi (2005)[54] | Physical self-concept | + | + | Self-concept (+)<br>Depression (–) |
| Casey et al (2014)[55] | Physical functioning | + | NR | Quality of life (+) |
| | Psychosocial functioning | + | NR | |
| | Perceived sport competence | NS | NR | |
| | Family support | NS | NR | |
| | Friend support | NS | NR | |
| Laberge et al (2012)[56] | Social competence | NS | NR | Self-esteem (NS) |
| | Interethnic relationships | NS | NR | |
| Lindgren et al (2011)[57] | Support barriers to exercise | NS | NR | General self-efficacy (+) |
| | Social barriers to exercise | NS | NR | |
| Daley et al (2006)[58] | Physical self-concept | + | NR | Self-esteem (+) |
| | Perceived sport competence | NS | NR | Depression (NS) |
| | Perceived fitness | NS | NR | Positive affect (NS) |
| | Physical appearance | + | NR | Negative affect (NS) |
| | Perceived strength | + | NR | |
| | Social competence | NS | NR | |
| Petty et al (2009)[59] | Physical appearance | + | — | Depression (–) |
| | Social acceptance | NS | NS | Self-esteem (+) |
| | Perceived sport competence | NS | NS | |
| Riiser et al (2014)[60] | Body image | + | NR | Quality of life (NS) |
| Schneider et al (2008)[61] | Perceived health | NS | NR | Self-esteem (NS) |
| | Perceived coordination | NS | NR | |
| | Perceived body fat | NS | NR | |
| | Perceived appearance | NS | NR | |
| | Perceived endurance | NS | NR | |
| | Perceived coordination | NS | NR | |
| | Perceived sport competence | NS | NR | |
| | Perceived flexibility | NS | NR | |
| Schranz et al (2013)[62] | Resistance training self-efficacy | + | NS | Self-esteem (+) |
| | Exercise self-efficacy | + | NS | |
| | Physical self-concept | N | NS | |
| Seabra et al (2014)[63] | Body image | + | NR | Self-esteem (+) |
| | Perceived sport competence | + | NR | |
| Velez et al (2010)[64] | Perceived sport competence | + | NR | Self-esteem (+) |
| | Perceived fitness | + | NR | |
| | Perceived body attractiveness | + | NR | |
| | Perceived strength | NS | NR | |
| | Physical self-concept | + | NR | |
| Ha et al (2015)[65] | Physical well-being | NS | NR | Psychological well-being (NS) |
| | Autonomy and parent relation | + | NR | |
| | Peer and social support | NS | NR | |
| | School environment | NS | NR | |
| Robinson et al (2010)[66] | Body shape dissatisfaction | NS | NR | Depression (–)<br>Self-esteem (NS) |
| Kriemler et al (2010)[67] | Physical quality of life | NS | NR | Quality of life (NS) |
| Ebbeck and Gibbons (1998)[68] | Perceived athletic competence | + | NR | Self-esteem (+) |
| | Perceived physical appearance | + | NR | |
| | Social acceptance | + | NR | |
| Maïano et al (2007)[69] | Physical self-worth | NS | NR | Self-esteem (NS) |
| | Perceived fitness | NS | NR | |
| | Perceived sport competence | NS | NR | |
| | Perceived physical attractiveness | NS | NR | |
| | Perceived strength | NS | NR | |
| Marsh and Peart (1988)[70] | Perceived sport competence | + | NR | Self-esteem (NS) |
| | Perceived physical appearance | + | NR | |
| | Relations with same sex peers | NS | NR | |
| | Relations with opposite sex peers | NS | NR | |
| del Valle et al (2010)[71] | Physical function | NS | NR | Vitality (NS) |
| | Physical role | NS | NR | Emotional role (NS) |

**TABLE 2** Continued

| Study | Potential Mechanisms | Physical Activity Effect on Mechanism | Changes in Mechanism and Changes in Mental Health | Physical Activity Effects on Mental Health Outcomes |
|---|---|---|---|---|
| | Pain | NS | NR | Mental health (NS) |
| | General health | NS | NR | |
| | Social function | NS | NR | |
| | Physical component scale | NS | NR | |

+, significant increase or association; —, significant decrease or association; NS, nonsignificant ($P \geq .05$) for group-by-time interaction; NR, not reported.

**TABLE 3** Physical Activity Intervention Effects on Behavioral Mechanisms and Mental Health Outcomes

| Study | Potential Mechanisms | Physical Activity Effect on Mechanism | Changes in Mechanism and Changes in Mental Health | Physical Activity Effects on Mental Health Outcomes |
|---|---|---|---|---|
| Laberge et al (2012)[56] | Self-control | NS | NR | Self-esteem (NS) |
| Lakes and Hoyt (2004)[72] | Cognitive self-regulation | + | NR | Emotion difficulties (NS) |
| | Affective self-regulation | + | — | Conduct difficulties (NS) |
| | Physical self-regulation | + | — | Hyperactivity (NS) |
| | Freedom from distractibility | NS | — | Peer problems (NS) Prosocial (+) |

+, significant increase or association; —, significant decrease or association; NR, not reported; NS, nonsignificant ($P \geq .05$) for group-by-time interaction.

corresponding to neurobiological, psychosocial, and behavioral hypotheses previously described. The strongest evidence was found for improvements in physical self-perceptions that accompanied enhanced self-esteem in the majority of studies measuring these outcomes. Few studies examined neurobiological (eg, brain structure and functioning) and behavioral (eg, self-regulation) mechanisms. In addition, due to study heterogeneity, we were unable to draw firm conclusions regarding these mechanistic pathways.

## Risk of Bias Summary

Overall, the risk of bias for included studies was mixed, with approximately one-half of studies failing to satisfy ≥50% of the criteria. Although no studies included blinded participants or intervention facilitators, it is important to recognize that these criteria are difficult to satisfy in the context of physical activity interventions. Perhaps more importantly, only 1 in 5 studies reported the blinding of assessors during data collection. In physical activity trials, this action is a common and meaningful source of bias,[74] which should be addressed in future research.

## Neurobiological Mechanisms

Experimental studies examining neurobiological mechanisms have emerged in the last 5 years, and additional studies will continue to emerge as technology becomes more available. Existing studies have investigated different aspects of the brain by using a variety of methods (eg, MRI, fMRI, electroencephalography, event-related potential) and, consequently, the effect of any specific brain-related mechanism on improved cognitive function remains unclear. Hillman et al[7] found that a 9-month physical activity intervention aimed at improving cardiorespiratory fitness resulted in improved performance, as well as increased attentional resources on tasks requiring improved inhibition and cognitive flexibility. Furthermore, Chaddock-Heyman et al[50] found decreased fMRI activation of the right anterior prefrontal cortex, mirroring a more mature or adult-like activation pattern in a subsample of children participating in a physical activity intervention.

By contrast, changes in brain activation patterns did not correspond with between-group differences in cognitive control after an 8-month exercise trial with overweight children.[52] It is important to note that the study conducted by Davis et al[22] involved overweight/obese children and used the anticascade task, whereas the participants in the study by Hillman et al[7] were of a healthy weight status and a flanker task was used. Of note, these tests tap into different aspects of inhibitory control (perceptual interference versus behavioral inhibition), and it is unclear that the 2 studies should corroborate one another.

Future studies should aim to replicate the findings of previous research and test the transferability of these findings into real-world settings (eg, schools). Because none of the studies included in the review targeted adolescents, there is a strong rationale for examining neurobiological mediators in this population. Indeed, should clear evidence of the efficacy of physical activity programs for improving cognition become available, the question of timing will be a critical factor for educators and physical activity researchers alike. Whether childhood or adolescence offers greater potential for improving cognitive functioning would clearly be of interest, and more experimental evidence from across the age spectrum would help shed light on this question.

### Psychosocial Mechanisms

There was evidence for a causal link between physical self-perceptions and indicators of well-being (eg, self-concept, self-esteem). Of note, changes in appearance self-perceptions coincided with improvements in self-esteem in 5 of the 6 studies evaluating these constructs together. Similarly, improvements in physical self-concept and perceived competence coincided with improvements in self-esteem in 2 of 3 studies and 3 of 4 studies, respectively. These findings are consistent with the predictions of the Exercise and Self-Esteem Model[30] and the Shavelson model of self-concept.[31] As previously described, improvements in specific physical self-perceptions (eg, perceived sport competence) are hypothesized to generalize to improvements in overall physical self-concept and ultimately to enhanced self-esteem. According to the theory, improvements in self-esteem should be expected in the presence of positive changes in self-perceptions or self-concept. Encouragingly, this outcome is what was observed in the majority of these studies. In 1 study,[59] the effect of an aerobic exercise intervention on depressive symptoms among overweight children was partially mediated by changes in perceived appearance and global self-worth. This study suggests that perceptions of the self are indeed related to ill-being in youth.

Connectedness with others is universally accepted as an important component of well-being, and this construct features prominently in current psychological theories.[24–26] In the studies included in the current review, relatedness was often operationalized as "social acceptance" (ie, the belief that one is valued and accepted by others). Social acceptance was measured in 3 studies,[58,59,68] and each of these studies also examined the effects of interventions on self-esteem. Interestingly, although significant intervention effects were reported for social acceptance in only 1 study,[58] improvements in self-esteem were found in all 3 studies. Considering the recognized importance of this construct for well-being, this finding is perhaps surprising. However, individuals can have strong feelings of social connectedness, and at the same time perceive themselves as physically unattractive and incompetent in sport and exercise settings. In such cases, these individuals would have little capacity to improve feelings of social acceptance through participation in a physical activity program.

### Behavioral Mechanisms

No relevant studies investigating sleep-related variables were identified through the search, highlighting a clear gap in the literature. Only 2 studies investigated the effects of interventions on self-regulation skills, and the findings were mixed. For example, Lakes and Hoyt[72] reported positive effects on cognitive, affective, and physical self-regulation skills after a 3-month school-based martial arts training intervention. Conversely, Laberge et al[56] found no effect for self-control among underserved adolescents participating in a physical activity intervention targeting the school lunch hour. In addition, neither study reported positive effects for mental health indicators.

As illustrated, there is a clear lack of studies examining the effect of potential behavioral mechanisms on changes in mental health. It is plausible that the adoption of behavioral management strategies could assist young people to feel more in control, and hence more satisfied with their lives. Not included in our original search, but worthy of investigation, are academic behaviors (distinct from academic performance), such as time on task[75] and homework completion; these behaviors may improve after participation in physical activity.[73] Additional behaviors, such as drug taking (eg, smoking and alcohol), diet, and recreational screen-time may also mediate the effect of physical activity interventions on cognitive and mental health outcomes.

### Limitations of the Current Review

A small number of studies satisfied our eligibility criteria, and there was considerable heterogeneity among studies. It is likely that there are other neurobiological, psychosocial, and behavioral variables not included within our conceptual model that might explain cognitive and mental health outcomes in young people. Therefore, our conceptual model should not be considered a complete picture but rather an important starting point to be reconciled through future research. It is important to note the following possibilities: (1) there may be a bidirectional relationship between physical activity and mental health; and (2) multiple independent mechanisms may influence mental health outcomes in parallel or via interaction with each another.

### Summary of Research Recommendations

None of the studies included in this review examined potential mechanisms using an accepted statistical mediation analysis technique.[76] To enable robust meta-analyses, future studies should report standardized regression coefficients for the following: (1) the effect of interventions on potential mechanisms; (2) the effect of interventions on mental health outcomes; and (3) the association between changes in potential mechanisms and changes in mental health outcomes. Researchers are encouraged to answer the following research questions and provide support for our conceptual model.

### *Neurobiological Questions*

- What are the specific brain structures/networks and cognitive functions most influenced by physical activity?
- How does varying the intensity of physical activity differentially alter the effects on brain structure and function?

### *Psychosocial Questions*

- How can the design and delivery of physical activity interventions be maximized to enhance their effect on physical self-perceptions?
- What is the relative importance of participant experience of the physical activity intervention and the physiologic dose received?
- What is the role of social interaction in a physical activity context for affecting mental health?
- What influence does the natural environment have on enhancing the mental health benefits of physical activity for young people?

### *Behavioral Questions*

- What is the role of sleep as a mediator for the effect of physical activity on cognitive function, well-being, and ill-being?
- What type of physical activity supports academic behaviors (eg, time on task and homework completion) and subsequent cognitive development?
- Can improvements in motor skill proficiency enhance cognitive outcomes?

## CONCLUSIONS

Systematic reviews and meta-analyses have shown that physical activity interventions can improve cognitive and mental health in young people, but our review identified a lack of available evidence for the specific mechanisms responsible for these effects. However, our review has established that participation in physical activity can improve physical self-perceptions and enhance self-esteem in young people. Our findings highlight several important gaps in the research literature and emphasize the need for more high-quality experimental research to examine the specific paths of influence between physical activity participation and improved mental health. In particular, future studies should conduct statistical mediation analyses, using the conceptual model provided herein as a framework. Improving our understanding of how physical activity improves mental health in child and adolescent populations may assist in the design of interventions to optimize their possible impact on these critically important outcomes. Finally, elucidating the mechanisms underpinning the effect of physical activity on cognition, well-being, and ill-being may provide the necessary impetus for schools, governments, and policy makers to prioritize physical activity promotion.

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### ABBREVIATIONS

fMRI: functional MRI
RCT: randomized controlled trial

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Address correspondence to David Lubans, PhD, Priority Research Centre for Physical Activity and Nutrition, University of Newcastle, University Drive, Callaghan NSW, Australia 2308. E-mail: david.lubans@newcastle.edu.au

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**Physical Activity for Cognitive and Mental Health in Youth: A Systematic Review of Mechanisms**

David Lubans, Justin Richards, Charles Hillman, Guy Faulkner, Mark Beauchamp, Michael Nilsson, Paul Kelly, Jordan Smith, Lauren Raine and Stuart Biddle

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