

Creative Flow in Motion: The Impact of Physical Exercise on Creative Thinking

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Date: 2022-09-21T00:00:00+00:00

Abstract

Creative thinking is a cognitive form that employs unique and novel perspectives to solve problems, with divergent and convergent thinking representing two common types. Physical exercise exerts differential effects on divergent and convergent thinking, which are moderated by factors including exercise intensity, modality, duration, and individual differences. Current theories explaining how physical exercise influences creative thinking encompass the affective hypothesis, executive function hypothesis, and embodied metaphor theory. Future research should, while further emphasizing methodological rigor, strengthen neuroscientific investigations and expand population coverage, examine the relationship between physical exercise and creative achievement, and provide robust scientific support for exercise prescriptions targeting creative thinking.

Full Text

Legs Move, Thoughts Flow: Physical Exercise Influences Creative Thinking

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Abstract

Creative thinking is the cognitive process of solving problems using unique and novel perspectives, with divergent and convergent thinking representing two common types. Physical exercise exerts differential effects on divergent and convergent thinking, moderated by factors such as exercise intensity, modality, duration, and individual differences. Current theories explaining how physical exercise influences creative thinking include the mood hypothesis, executive

function hypothesis, and embodied metaphor theory. Future research should emphasize methodological rigor, strengthen neuroscientific investigations, broaden population coverage, and examine the relationship between physical exercise and creative achievement to provide robust scientific support for prescribing exercise regimens for creative thinking enhancement.

Keywords: physical exercise, creative thinking, divergent thinking, convergent thinking

2 Physical Exercise Influences Creative Thinking: A Divergent and Convergent Perspective

Creative thinking encompasses two fundamental cognitive processes: divergent and convergent thinking (Guilford, 1967). Physical exercise produces differential effects on these two processes, and the following sections elaborate on how exercise influences creative thinking from the perspective of divergent and convergent thinking.

2.1 The Effects of Physical Exercise on Divergent Thinking

Divergent thinking refers to the cognitive process of generating diverse outcomes from existing information through novel and unique perspectives (Shen et al., 2016). It comprises three essential components: fluency, flexibility, and originality (Guilford, 1967), which respectively reflect the quantity, variety, and quality of ideas (Duan, 1986; Benedek et al., 2012). Physical exercise may differentially affect these components, with stronger facilitative effects on flexibility and originality (Venditti et al., 2015; Ludyga et al., 2020) but minimal impact on fluency (Matsumoto et al., 2022).

Some researchers propose that exercise can enhance flexibility and originality by depleting cognitive control resources. For instance, Oppezzo and Schwartz (2014) used the Alternative Uses Task (AUT) to measure changes in divergent thinking after sedentary sitting and walking, finding that walking significantly enhanced divergent thinking compared to sitting, with outdoor walking showing greater improvement in flexibility and originality than treadmill walking. Given that free walking consumes more cognitive control resources than constrained walking (Brisswalter et al., 1995), Oppezzo and Schwartz speculated that improvements in flexibility and originality might be related to cognitive resource depletion. However, this study could not conclusively demonstrate that enhanced divergent thinking resulted from cognitive depletion, as factors such as movement amplitude and environmental context could confound the results. To further investigate the relationship between cognitive control depletion and divergent thinking, Zhou et al. (2017) introduced three physical intervention postures: lying down, sitting, and standing, each involving no bodily movement but progressively increasing cognitive control demands. The results showed that even after controlling for movement amplitude and environmental interference, flexibility and originality levels still increased with greater cognitive control de-

pletion, confirming the facilitative role of cognitive control depletion in idea generation. This study argues that post-exercise cognitive control depletion leads to attentional defocusing and weakened top-down control, allowing more irrelevant information to enter consciousness and subsequently inspiring more flexible and original ideas.

Additionally, exercise may promote originality by alleviating stress and enhancing well-being (Rominger et al., 2022; Steinberg et al., 1997). Campion and Levita (2014) found that after a 5-minute dance intervention, only participants with high well-being and low fatigue showed improved originality, suggesting a possible link between originality and well-being. Another study investigating the effects of 20 minutes of dance on divergent thinking in college students found that originality scores significantly increased after dancing, with psychological detachment serving as a mediator. This demonstrated that exercise can improve originality by inhibiting negative experiences and preventing excessive depletion of psychological resources (Bollimbala et al., 2022).

However, multiple studies have shown that physical exercise is unrelated to fluency. Perchtold-Stefan et al. (2020) used the Freiburger Questionnaire on Physical Activity and the Reappraisal Inventiveness Test (RIF) to survey exercise levels and affective divergent thinking abilities in 98 students, finding no association between weekly time spent on physical activity and the total number of creative ideas. Another intervention study yielded similar results: Bollimbala et al. (2020) randomly assigned participants to complete either 20 minutes of exercise training or academic research, measuring divergent thinking before and after exercise. The results showed that exercise only improved flexibility and originality, with no effect on fluency. These findings may be related to the nature of the thinking process. Research demonstrates that physical exercise can enhance the processing efficiency of executive functions, and that exercise only shows positive effects when cognitive tasks involve high executive control demands (Bae & Masaki, 2019). Fluency in divergent thinking tasks reflects the number of ideas, representing the lowest-level component of divergent thinking with simple execution processes and minimal cognitive control demands. Therefore, improvements in executive function efficiency have limited impact on fluency, making the facilitative effect of exercise difficult to manifest.

In summary, physical exercise differentially affects the components of divergent thinking, with stronger effects on flexibility and originality but weaker effects on fluency. Through mechanisms such as cognitive control resource depletion and stress alleviation, physical exercise can elicit optimal performance in flexibility and originality. However, fluency involves relatively simple control processes, so the enhanced cognitive functions from exercise cannot be adequately expressed in this component.

2.2 The Effects of Physical Exercise on Convergent Thinking

Convergent thinking is the cognitive process through which individuals utilize acquired knowledge and experience to analyze, reason, and derive optimal answers and strategies from known information (de Rooij & Vromans, 2020). Convergent thinking aims to obtain a single best answer, often measured by success rates in creative problem-solving (Aga et al., 2021; Baker et al., 2019). Research on the relationship between physical exercise and convergent thinking shows considerable disagreement, with most studies reporting detrimental or null effects, though some have documented beneficial impacts.

Multiple studies demonstrate that exercise negatively affects convergent thinking. Colzato et al. (2013) used a pretest-posttest design with athletes and non-athletes to investigate the relationship between moderate-to-high intensity exercise and convergent thinking, finding that after high-intensity exercise, non-athletes showed significantly reduced scores on the Remote Association Test (RAT), indicating that physical exercise interfered with insight problem-solving ability. Similarly, Baker et al. (2018) found that insight problem-solving accuracy was severely impaired during pedaling exercise. Two possible explanations exist for this result. First, from a cognitive control perspective, convergent thinking requires strict searching for optimal answers, a process demanding extremely high cognitive control. Post-exercise physical fatigue can lead to cognitive control failure, subsequently impairing convergent thinking performance (Bialystok & Craik, 2010; Colzato et al., 2013). Second, from an emotional regulation perspective, positive affect may be a necessary condition for enhanced convergent thinking. Previous researchers' failure to find improvements in convergent thinking might be due to exercise interventions that did not elicit emotional changes. This speculation is supported by empirical research: Aga et al. (2021) randomly assigned participants to 15 minutes of exercise or a control intervention, measuring insight problem-solving ability and post-exercise emotional experiences. The results showed that exercise effects on insight problem-solving depended on affect, with participants showing positive affect demonstrating enhanced insight problem-solving, while those showing negative affect exhibited diminished ability.

Some studies have failed to find relationships between exercise and convergent thinking, possibly due to the intensity of exercise interventions used. These studies typically employed moderate or low-intensity exercise. For example, Frith and Loprinzi (2018) found no significant changes in RAT scores after moderate-intensity aerobic exercise training. Jung et al. (2021) found that low-intensity walking had no effect on verbal, mathematical, or spatial insight problem-solving. Research indicates that tasks with high cognitive demands require more vigorous exercise to show effects (Tomprowski, 2003). Convergent thinking tests demand greater cognitive control and involve more top-down processing; moderate and low-intensity exercise do not consume sufficient cognitive control resources to trigger changes in higher-order cognitive functions and therefore cannot influence convergent thinking.

Notably, under certain specific experimental conditions, researchers have reported facilitative effects of exercise on convergent thinking. For instance, Frith et al. (2020) randomly assigned participants to a priming group or control group for 15 minutes of running, with the priming group receiving an anagram task to provide semantic priming for the RAT test. The results showed that compared to the control group, the priming group exhibited significantly enhanced insight problem-solving ability under semantic priming effects. The study argues that the flow of mental states activated by exercise, combined with semantic associative cues, provides sufficient neural stimulation to fully activate problem-solving strategies, thereby supporting insight problem-solving performance. Thomas and Lleras (2009) randomly assigned participants to perform either lateral arm extensions or forward-backward swinging movements, then measured insight problem-solving ability through the two-string task. The swinging group found the solution more quickly (by swinging to tie the ropes together). Moreover, most participants reported in post-experiment surveys that they were unaware of the connection between arm movements and problem solutions, indicating that when movement patterns align with problem solutions, bodily actions can implicitly provide cues for cognitive tasks, thereby enhancing insight problem-solving ability. These studies suggest that exercise effects on convergent thinking may depend on certain cognitive guidance; simple physical activity alone is insufficient to improve such advanced thinking forms. To access more complex, higher-order thinking, exercise must be supplemented with certain cognitive cues to maximize its effects.

In summary, researchers have not reached consensus on the relationship between physical exercise and convergent thinking. Exercise may trigger cognitive control failure and impair higher-order thinking processes, thereby weakening convergent thinking. Some researchers have used exercise interventions with insufficient intensity, failing to activate neural mechanisms related to convergent thinking and thus finding no association. However, numerous studies have discovered facilitative effects of exercise on convergent thinking, all emphasizing the important role of positive cognitive guidance.

3 Moderating Factors in the Effects of Physical Exercise on Creative Thinking

As research has progressed, investigators have found that exercise effects on creative thinking are highly complex, with results potentially moderated by exercise intensity, modality, duration, and individual differences. The following sections elaborate on the moderating effects of these factors.

3.1 Exercise Intensity

The effects of physical exercise on creative thinking exhibit intensity dose-response relationships, with optimal intensity for promoting creative thinking varying across different exercise frequencies. In acute exercise, current research

generally supports an inverted-U relationship between exercise intensity and creative thinking performance, with both excessively high and low intensities showing disadvantages. For example, Baker et al. (2019) found that low-intensity exercise produced no significant changes in divergent thinking levels compared to pre-exercise baseline. Another study reported that single-session high-intensity exercise caused exhaustion, subsequently impairing both divergent and convergent thinking (Colzato et al., 2013). However, moderate-intensity acute exercise yields maximal benefits for creative thinking (Blanchette et al., 2005; Loprinzi & Kane, 2015; Frith et al., 2019; Nakagawa et al., 2020). Moderate-intensity exercise can induce appropriate physiological arousal without reaching exhaustion and causing cognitive control failure, thereby maximizing facilitative effects. Notably, even moderate-intensity acute exercise produces unstable improvements in creative thinking (Donnegan et al., 2018; Patterson et al., 2018), as single-session exercise only produces quantitative changes in psychological and neural functions, making facilitative effects less apparent.

In chronic exercise, high-intensity exercise is more conducive to creative thinking enhancement (Ruiz-Ariza et al., 2017; Román et al., 2021; Tilp et al., 2019). High-intensity exercise is more closely associated with psychological and physiological changes (Hötting et al., 2016), and through improvements in cognitive functions such as working memory, attention, and executive control (Venditti et al., 2015; Ludyga, Gerber, Pühse et al., 2020; Erickson et al., 2019) and changes in neural functions like brain plasticity (Ben-Soussan et al., 2015; Schmidt-Kassow et al., 2012), high-intensity chronic exercise can produce persistent and stable facilitative effects on creative thinking.

In conclusion, optimal exercise intensity differs across exercise frequencies. In acute exercise, moderate intensity is most beneficial for creative thinking enhancement, though this effect is unstable. In chronic exercise, high-intensity exercise establishes closer connections with physiological mechanisms, thereby producing persistent and stable influences on creative thinking.

3.2 Exercise Modality

Current research on physical exercise and creative thinking has employed two types of exercise modalities: constrained exercise and free exercise. Constrained exercise involves movements restricted by researcher instructions, most commonly aerobic exercise (e.g., walking, running, yoga). Free exercise allows participants to move in different ways without movement restrictions. Research shows that free exercise elicits greater creative potential than constrained exercise, particularly for divergent thinking. For example, Kuo and Yeh (2016) compared individuals' divergent thinking levels during rectangular-path walking versus free walking, finding improvements only in the free walking group. Similarly, Richard et al. (2020) randomly assigned participants to 30 minutes of aerobic dance, free dance, or reading, finding that the free dance group showed significantly greater enhancement in divergent thinking than the aerobic dance

group.

Researchers have explained the differential effects of free versus constrained exercise on divergent thinking from different perspectives. On one hand, free exercise involves the integration of motor perception and conceptual representation. Compared to walking along prescribed paths, individuals walking freely show stronger “thinking outside the box” abilities (Leung et al., 2012). Because motor perception is linked to abstract conceptual representations (freedom, lack of constraint), this mind-body connection catalyzes more flexible and original ideas (Richard et al., 2021). On the other hand, researchers have proposed attentional effects in free exercise. Murali and Händel (2022) found that free-walking participants scored higher on the AUT test than those in constrained conditions, with blink frequency during free states significantly correlating with AUT scores. Murali and Händel speculated that free states expand attentional scope and conceptual perception, facilitating flexible switching between concepts and thereby promoting divergent thinking performance.

In summary, compared to constrained exercise, free exercise can elicit stronger divergent thinking potential. On one hand, variations in bodily activity during free exercise convey more flexible and diverse sensorimotor information to the mind, cueing individuals to generate multiple and novel ideas. On the other hand, the expanded attentional scope in free states biases the thinking system toward flexibility, demonstrating stronger divergent thinking.

3.3 Exercise Duration

Exercise duration is an important moderating variable affecting intervention outcomes, and its effect is independent of other dose parameters such as intensity and frequency (Singh et al., 2019). Given that temporal paradigms describe the timing of cognitive testing during exercise interventions and provide more specific information about exercise duration (Chang et al., 2012), researchers tend to examine the role of exercise duration across different temporal paradigms. Current research uses two temporal paradigms: simultaneous paradigms, where creative tests are completed during exercise, and sequential paradigms, where creative tests are completed after exercise.

In simultaneous paradigms, exercise duration should not be too short. Jung et al. (2022) employed a 20-minute exercise intervention and found no significant changes in convergent thinking scores during exercise compared to pre-exercise baseline. Colzato et al. (2013) observed decreased creative thinking during a 13-minute exercise intervention. A meta-analysis found that beneficial effects on cognitive functions only gradually emerged after at least 20 minutes of exercise (Chang et al., 2012). However, most studies have used intervention durations of 5-15 minutes and therefore failed to observe changes in creative thinking. Notably, excessively long exercise also produces detrimental effects. Baker et al. (2018) implemented a 2-hour low-intensity exercise intervention, collecting convergent thinking data five times during the session. The results showed

that convergent thinking test scores increased during the first 30 minutes of exercise but error rates significantly increased after 30 minutes, accompanied by deteriorated mental states and muscle fatigue. Based on these findings, optimal exercise duration in simultaneous paradigms appears to be 20-30 minutes, with both too-short and too-long durations hindering creative thinking.

In sequential paradigms, exercise lasting from 5 minutes to 1 hour has facilitative effects on various creative thinking indicators (Chen et al., 2021; Aga et al., 2021; Bae & Masaki, 2019; Román et al., 2018), with effects showing some temporal delay. Zhao et al. (2022) implemented a 25-minute exercise intervention and measured creative thinking at 5 and 30 minutes post-exercise. The results showed that both divergent and convergent thinking significantly improved at 5 minutes post-exercise compared to pre-exercise baseline, but these effects disappeared within 30 minutes post-exercise. However, another study using a 35-minute exercise intervention found a 1-hour delayed effect (Netz et al., 2009). These studies indicate that as post-exercise rest time increases, the facilitative effects of exercise on creative thinking gradually diminish, though increasing exercise intervention duration may extend the duration of effects.

In summary, in simultaneous paradigms, exercise intervention duration should be neither too short nor too long, with 20-30 minutes being optimal. In sequential paradigms, exercise lasting from 5 minutes to 1 hour can improve creative thinking generation, with effects gradually decreasing over time post-exercise until disappearance, though appropriate increases in exercise duration can extend effect duration.

3.4.1 Age

Participant age is a primary moderating factor. Physical exercise can effectively improve creative thinking performance in adolescents and older adults (Román et al., 2017; Netz et al., 2007), yet some studies report no relationship between creative thinking and exercise in early adulthood (Main et al., 2020; Patterson et al., 2018). Meta-analyses have found smaller effects of exercise on cognitive functions in early adulthood (Ludyga et al., 2016). This may be because early adulthood individuals exhibit ceiling effects on creative thinking tests. Young individuals show extremely strong higher-order cognitive functions, but the creative thinking tasks used in experiments may be too simple for physical exercise to produce improvement.

Additionally, exercise effects on children at different developmental stages warrant investigation. Piya-amornphan et al. (2017) collected daily physical activity levels from 1,477 students via questionnaire and failed to find relationships between physical activity and creative thinking in 6-13-year-old children. This result may be related to children's age characteristics. Around age 9 is when children transition from pre-conventional to conventional stages, showing appreciation for and compliance with social conventions (Runco et al., 2014), which may hinder creative thinking. However, this does not mean exercise can-

not be effective. Richard et al. (2018) assigned children with a mean age of 9.56 years to either a traditional curriculum group or an innovative curriculum group. The traditional group participated in conventional technical sports training, while the innovative group participated in sports training incorporating problem-solving and improvisation activities based on technical learning. The results showed that creative thinking significantly increased in the innovative curriculum group but decreased in the traditional group. This study demonstrates the important role of environment: even when children at this age show lower creativity, sports in innovative environments can still produce positive effects. Therefore, how physical exercise stimulates creative thinking in developmentally changing individuals warrants further investigation.

In summary, compared to adolescents and older adults, physical exercise has smaller effects on creative thinking in early adulthood because young individuals' cognitive abilities are at lifetime peaks, producing ceiling effects on creative tests. Compared to other age groups, exercise effects are difficult to demonstrate in 6-13-year-old children because this age group is undergoing developmental changes, with creative thinking constrained by declining social convention adherence, though providing innovative environments can still enable exercise to exert facilitative effects.

3.4.2 Physical Fitness

The effects of physical exercise on creative thinking are also moderated by physical fitness. Current research on fitness factors primarily falls into two categories: physical health and exercise habits.

Regarding the relationship between physical health and creative thinking, healthy individuals are generally believed to have higher creativity levels (Román et al., 2017), but this view has been questioned in physical exercise research. Ramocki et al. (2002) found that regardless of physical health status, physical exercise produced equitable beneficial effects on individuals' divergent thinking abilities, suggesting that exercise effects on divergent thinking are independent of physical health. This result may be related to thinking type. Themanson et al. (2006) found that healthy individuals only exceeded sub-healthy individuals in top-down control abilities. Therefore, health status shows non-significant effects on divergent thinking but may benefit convergent thinking processes. Some studies have demonstrated that healthy participants with good health indicators such as grip strength and Body Mass Index (BMI) showed greater post-exercise insight problem-solving improvements (Aga et al., 2021; Bollimbala et al., 2019), indirectly indicating potential beneficial effects of physical health on convergent thinking. Additionally, exercise may show reverse dose effects. For example, Ruiz-Ariza et al. (2017) and Netz et al. (2009) both found that individuals with lower fitness levels actually showed stronger post-exercise divergent thinking, possibly because lower-fitness individuals perceive higher exercise stimulation and produce stronger neural excitation levels.

Regarding exercise habits, individuals with regular exercise habits show greater convergent thinking improvements during exercise compared to sedentary individuals (Colzato et al., 2013). This result may be related to energy sense. Specifically, exercise habits are closely related to energy sense (Ward-Ritacco et al., 2015), and energy sense mediates the relationship between physical exercise and cognitive function (Legrand et al., 2018). Individuals with exercise habits experience increased energy sense during exercise, improving creative thinking processes, while sedentary individuals experience decreased energy sense during exercise, weakening creative thinking performance. Additionally, Colzato et al. found that during post-exercise rest, athletes actually scored worse than non-athletes on divergent and convergent thinking tests. The possible reason is that physical exercise is a pleasurable activity for individuals with exercise habits, so continued exercise facilitates divergent and convergent thinking performance, while rest (cessation of exercise) inhibits pleasurable experiences, leading to declines in divergent and convergent thinking.

In summary, physical fitness levels can moderate exercise effects. Regarding physical health, compared to sub-healthy individuals, healthy individuals show stronger top-down control abilities that benefit convergent thinking performance but have minimal effects on divergent thinking. Regarding exercise habits, individuals with exercise habits show higher convergent thinking levels than sedentary individuals due to stronger energy sense and pleasurable experiences, though this effect disappears after exercise when pleasurable experiences cease.

4 Theoretical Explanations for the Effects of Physical Exercise on Creative Thinking

Currently, several perspectives exist regarding the psychological mechanisms through which physical exercise influences creative thinking: the mood hypothesis, executive function hypothesis, and embodied metaphor theory.

4.1 Mood Hypothesis

This hypothesis posits that physical exercise influences creative thinking by altering mood. Specific viewpoints can be divided into two types. The first considers only affective valence, proposing that physical exercise can activate positive or negative emotions, with positive emotions facilitating creative thinking and negative emotions inhibiting it (Rominger et al., 2022). Specifically, positive emotions promote relaxed cognitive processing modes, simplifying information processing by enhancing broad connections among positive representations in long-term memory, enabling individuals to gain richer, more diverse information while improving cognitive processing efficiency, thereby facilitating divergent and convergent thinking processes (Baas et al., 2008). Conversely, negative emotions cue tense cognitive processing modes, shifting cognitive resources from creativity to defense mechanisms and enabling systematic, detailed information processing styles that inhibit creativity (Zhang et al., 2017). The

second viewpoint also considers arousal level, proposing that the facilitative effect of emotions on creativity is determined by emotional arousal level, with both activated (rather than deactivated) positive and negative emotions enhancing creative thinking through different pathways (Dreu et al., 2008). The former enhances creative thinking by increasing cognitive flexibility and inclusiveness, while the latter promotes creative thinking by inducing cognitive persistence and sustained thinking. However, no studies have yet confirmed the mediating role of mood between physical exercise and creative thinking (Steinberg et al., 1997; Rominger et al., 2020; Aga et al., 2021), with most studies only considering affective valence or activation effects. Future research could simultaneously combine both dimensions for further investigation.

4.2 Executive Function Theory

Executive function, as a general control process regulating thoughts and behaviors, is closely related to creative thinking (Zabelina et al., 2019). Researchers believe executive function plays a crucial role in the process of exercise influencing creative thinking (Bollimbala et al., 2019). However, regarding whether exercise effects on creative thinking result from “weakening” or “enhancing” executive function, researchers have proposed different viewpoints.

Some researchers propose the role of “cognitive control depletion” in acute exercise (Colzato et al., 2013). Cognitive control resources represent the energy required for individuals to successfully execute cognitive processing, upon which various controlled cognitive operations depend (Li, 2013). Physical exercise, as a non-automatic activity, depletes cognitive control resources and produces opposite effects on subsequent divergent and convergent thinking tasks (Dorris et al., 2012). Divergent thinking benefits from cognitive control resource depletion. Reduced cognitive control resources lead to attentional defocusing, broadened attention scope, and increased attentional jumping, helping individuals obtain more seemingly irrelevant stimuli and gain creative insights (Memmert, 2012). Additionally, cognitive control depletion also leads to weakened top-down control, enhancing spreading activation, meaning that activation of one concept leads to activation of more related nodes. This broad information activation can effectively overcome functional fixedness and elicit more diverse and novel ideas (Radel et al., 2015; Zhou et al., 2017; Scibinetti et al., 2011). However, cognitive control depletion impairs convergent thinking performance because convergent thinking emphasizes logic, speed, and high precision, demanding high cognitive control. Reduced attention and top-down control directly lead to convergent thinking control failure.

Notably, numerous recent studies have found beneficial effects of exercise on executive function (Northey et al., 2018; Ishihara et al., 2021). Accordingly, some researchers argue that creative thinking improvements depend on enhancement of certain executive functions (Bollimbala et al., 2019). For example, research has found that physical exercise helps improve working memory capacity (Pontifex et al., 2009). Working memory is the primary resource controlling atten-

tion, responsible for maintaining task-relevant information and controlling memory search, playing a major role in information recombination during divergent thinking. Divergent thinking tasks require participants to think of alternative uses for common objects, where individuals must identify object characteristics and search memory for applications not directly related to those features—for instance, recognizing a car tire’s size and shape and considering its use as a picture frame (Benedek, 2014). Additionally, physical exercise may enhance cognitive inhibition function (Pastor et al., 2021), strengthening individuals’ ability to activate strongly relevant information, effectively filter irrelevant information, and inhibit activation of irrelevant responses (Scibinetti et al., 2011). This change may produce beneficial effects on convergent thinking processes. Based on these studies, the role of executive function in the relationship between exercise and creative thinking is highly complex and warrants further investigation.

4.3 Embodied Metaphor Theory

This theory, from an embodied cognition perspective, emphasizes the holism of physical exercise, where exercise as a dynamic unity involves interactions among bodily dynamics, cognition, emotion, and physical environment. Perceptual experiences of the body in the world provide primary content for thought, so concrete physical experiences influence how people construct subjective social reality, a process achieved through metaphor (Frith, Miller et al., 2019). Metaphor refers to the process of expressing concepts from one cognitive domain (concrete, physical) in another abstract cognitive domain, and physical exercise can influence divergent and convergent thinking through embodied metaphors (Leung et al., 2012; Wang et al., 2019). Specifically, in divergent thinking, the metaphorical effect of free exercise is strongest. Unstructured, unplanned free exercise conveys richer and more diverse sensorimotor information and maps this information onto abstract categories through metaphorical mapping, prompting individuals to develop new understandings of creative tasks (Slepian & Ambady, 2012; Andolfi et al., 2017; Imaizumi et al., 2020). For example, free walking is more beneficial for divergent thinking than treadmill walking (Oppezzo & Schwartz, 2014) because “freedom” is metaphorically linked with “divergence.” In convergent thinking, metaphorical effects are strongest when movement patterns align with problem solutions. The metaphorical effect of consistent movement on convergent thinking depends on cognitive cues provided by movement trajectories, where specific actions activate the same motor representations across different problem spaces. These representations unconsciously enter working memory, influencing spatial representation selection during insight problem-solving, thereby improving problem-solving strategies and promoting generation of specific ideas (Thomas & Lleras, 2009). For example, solving the nine-dot problem requires non-dot turning outside the nine-dot box to connect all nine dots with one line. Research has found that participants who previously received implicit motor training (arm non-dot turning movements) solved the nine-dot problem more efficiently because the “non-dot turning” motor representation was activated during problem-solving, subsequently optimizing

participants' solution strategies (Spiridonov et al., 2019).

5 Conclusions and Future Directions

This paper reviewed existing literature on physical exercise and creative thinking, examining moderating factors and psychological mechanisms underlying exercise effects on creative thinking. However, given unstable, complex, and diverse research findings on the relationship between physical exercise and creative thinking, and that many studies have focused on short-term exercise effects and single populations, future research can explore several directions for deeper investigation.

First, emphasize research standardization and scientific rigor while expanding research scope. The interacting influences of exercise intensity, frequency, modality, age, and physical fitness mentioned in this paper explain the inconsistent and variable relationship between physical exercise and creative thinking. However, some existing studies suffer from insufficient experimental control (Frith et al., 2019) and low scoring efficiency (Richard et al., 2020), which may enhance feasibility but compromise scientific rigor. Additionally, the relationship between physical exercise and creative thinking cannot be simply generalized, as factors such as individual intelligence levels, exercise preferences, and fatigue may produce additional effects (Fritz et al., 2020; Aga et al., 2021). Future research needs to strictly control extraneous variables, emphasize methodological standardization and scientific rigor, attend to other potential influences from exercise processes, and expand to non-intellectual factors of creative thinking, such as emotional creativity and creative personality.

Second, strengthen neuroscientific research on exercise and creativity to provide reliable evidence. Research shows that physical exercise can induce changes in physiological mechanisms including brain-derived neurotrophic factor (BDNF), brain structure, functional connectivity, and neurotransmitters (Thomas et al., 2012; Voelcker-Rehage & Niemann, 2013), mechanisms also considered closely linked to creative thinking (Jauk et al., 2015). The connection between human physiological and cognitive functions is dynamically complex, with some researchers speculating that physical exercise and cognitive resource allocation may activate the same neural pathways (Frith et al., 2019), though no studies have yet clarified this connection. Future research should strengthen neuroscientific investigations of the relationship between physical exercise and creative thinking to provide reliable evidence for deeply revealing the complex mechanisms through which exercise influences creativity.

Third, examine mechanisms of exercise effects on creative thinking across different populations. Current research subjects have primarily focused on adolescents and college students. Torrance (1981) proposed that exercise is an effective strategy for enhancing lasting creative thinking in young children. Meta-analyses indicate that divergent thinking is impaired in patients with Alzheimer's disease, and regular exercise can help alleviate dementia symptoms and aid rehabilita-

tion (Fusi et al., 2021). Therefore, it is necessary to expand research subjects to include young children and elderly populations. Moreover, future research should focus on special populations. For example, studies have found exercise can stimulate creative potential in children with Attention Deficit Hyperactivity Disorder (ADHD) (Ludyga et al., 2020), an effect worthy of further investigation. Regarding gender, some studies have found that physically active males show higher creative thinking in natural science, technology, and mathematics than females, while females have advantages in emotional creativity (Top & Akili, 2018), though this effect has not been confirmed in the physical exercise and creative thinking domain. Future research can conduct in-depth investigations of this topic.

Fourth, explore the relationship between physical exercise and creative achievement. Currey (2013) analyzed the daily routines of 161 renowned creators and found that most exercised regularly, suggesting a possible link between exercise habits and creative achievement. Writer Haruki Murakami deeply understands the benefits of exercise for his writing career, compiling his 30-plus years of running and creative experience into an autobiography: *What I Talk About When I Talk About Running*, repeatedly mentioning the important connection between creativity and running, believing that only during running do “momentary creative thoughts slip into the mind” (Murakami, 2009). Steve Jobs’ employees have also frequently mentioned his fondness for walking meetings, because thinking becomes more expansive while walking, allowing people to express ideas they cannot express in conference rooms (Isaacson, 2011). As described above, creators from art, literature, business, and science have all mentioned that exercise is an indispensable factor in their creative careers. Although some literature has demonstrated positive correlations between exercise experiences during adolescence and early adulthood and lifetime creative thinking levels (Lupu et al., 2012; Bowers et al., 2014), such research is extremely scarce, with most studies still focusing on immediate exercise effects. If exercise can only produce brief creative thinking enhancements, such results have limited practical significance. Future research should focus on exploring the long-term and even lifelong effects of exercise on creative thinking, identifying conditions under which exercise produces optimal facilitative effects on creative thinking, and combining this with daily life to provide theoretical foundations for exercise prescription and sports training program development to cultivate individuals’ lifelong creativity and provide public health recommendations for integrating physical exercise as a necessary factor into public life.

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