The Inhibitory Effect of Exercise Intervention on Aggressive Behavior and Its Mechanism of Action

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Abstract

This study investigates the multidimensional pathways and influencing factors through which exercise interventions curb aggressive behavior. Building upon four theoretical pathways—emotion regulation, cognitive control, social connection, and social identity—it proposes a dynamic interactive integrative model. From individual-level psychological modulation to group-level social interaction, the model systematically elucidates the comprehensive pathway by which exercise interventions suppress aggressive behavior via ameliorating emotional states, enhancing cognitive functions, strengthening behavioral synchronization, and augmenting group identity. The study further examines the moderating effects of exercise intervention type, cultural background, and individual characteristics on intervention efficacy, while delineating neural and physiological mechanisms as empirical underpinnings for these theoretical pathways. Additionally, it proposes that future research may incorporate novel technologies such as dynamic modeling to optimize model validation.

Full Text

The Inhibitory Effects of Exercise Intervention on Aggressive Behavior and Its Mechanisms

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Abstract: This study explores the multidimensional pathways and influencing factors of exercise interventions in inhibiting aggressive behaviors. Based on four theoretical frameworks—emotion regulation, cognitive control, social bonding, and social identity—we propose a Dynamic Interactive Comprehensive Model. This model systematically elaborates the comprehensive mechanisms through

which exercise interventions suppress aggression, ranging from individual-level psychological regulation to group-level social interactions. Specifically, it demonstrates how physical activities mitigate aggressive tendencies by improving emotional states, enhancing cognitive functions, strengthening behavioral synchronization, and reinforcing group identity. The study further analyzes moderating factors such as exercise types, cultural contexts, and individual characteristics that influence intervention effectiveness. It also examines the neurophysiological mechanisms underlying these theoretical pathways. Finally, we suggest that future research could employ advanced methodologies like dynamic system modeling to optimize model validation and theoretical refinement.

Keywords: Exercise intervention; Aggressive behavior; Emotion regulation; Cognitive control; Social connection; Group identity

Aggressive behavior refers to actions through which individuals cause harm or pose threats to others via verbal or physical means (Anderson & Bushman, 2002). Such behavior not only negatively impacts individual physical and mental health but also undermines social harmony and increases the risk of crime and violent incidents (Berkowitz, 1993). In recent years, effectively inhibiting aggressive behavior has become a critical issue in psychology and social sciences. Among various approaches, exercise intervention has gradually attracted attention from researchers and practitioners as a natural, low-cost, and easily implementable method. However, existing studies still exhibit considerable controversy and unresolved questions regarding the mechanisms of action and applicable scope of exercise interventions.

Exercise intervention refers to organized physical activities that improve individuals' emotional, cognitive, and social functioning to inhibit maladaptive behaviors (Cirelli et al., 2021). Numerous empirical studies have demonstrated that exercise interventions can significantly suppress aggressive behavior by improving emotional states, enhancing impulse control capabilities, and strengthening social connectedness (Hötting & Röder, 2013; Vasconcellos et al., 2020). For instance, an experimental study on college students found that those who engaged in short-term running exhibited significantly lower aggression scores in simulated conflict tasks compared to non-exercising controls (Huang et al., 2022). Team sports have also been shown to effectively suppress aggression triggered by group conflicts by enhancing trust and cooperation among members (Lopez et al., 2020; Humińska-Lisowska, 2024). Although these studies provide preliminary evidence for the inhibitory effects of exercise interventions on aggressive behavior, numerous theoretical and practical issues remain unresolved.

Current research primarily employs four theoretical frameworks to explain how exercise interventions inhibit aggressive behavior: emotion regulation theory, cognitive control theory, social connection theory, and social identity theory. Emotion regulation theory posits that exercise interventions reduce impulsive aggression by decreasing individuals' anxiety and anger levels (Gross, 2002). Cognitive control theory emphasizes that exercise enhances executive functions, thereby strengthening individuals' control over impulsive behaviors (Diamond,

2013). Additionally, social connection and social identity theories, from the perspective of group exercise, reveal that enhanced behavioral synchronization and group belonging inhibit aggression by reducing intra- and inter-group conflicts (Hove & Risen, 2009; Tajfel & Turner, 1979). These theories provide important foundations for understanding the effects of exercise interventions. However, single theoretical pathways have limitations, and the inhibitory effects of exercise interventions on aggressive behavior likely require the synergistic integration of multiple pathways.

Moreover, existing research predominantly focuses on single levels (individual or group) and short-term intervention effects. How exercise interventions form dynamic interactive effects across individual and group levels to systematically inhibit aggressive behavior remains underexplored. For example, are the contributions of different mechanisms consistent across individual and group exercises? How do individual-level and group-level mechanisms interactively influence aggressive behavior? And how do cultural backgrounds and exercise types moderate these mechanisms? Answers to these questions are crucial for optimizing exercise intervention protocols.

Based on this background, this paper systematically examines the pathways through which exercise interventions inhibit aggressive behavior, particularly focusing on emotion regulation and cognitive control at the individual level, and social connection and social identity at the group level. It also analyzes their applicability across different populations and cultural contexts. By integrating these four pathways, this paper proposes a Dynamic Interactive Comprehensive Model to reveal the underlying logic of how exercise interventions inhibit aggressive behavior across multiple levels and pathways, providing a new theoretical framework and practical recommendations for future research.

2.1 Effects of Exercise Intervention on Aggressive Behavior

Numerous studies have demonstrated that both individual and group exercises exert significant inhibitory effects on different types of aggressive behavior, with effects varying between short-term and long-term interventions (Cirelli et al., 2021; Yang & Zeng, 2023).

First, the significant inhibitory effects of exercise intervention on aggressive behavior have been supported by empirical research. A study on adolescents found that after a 12-week aerobic exercise intervention, participants exhibited fewer verbal and physical aggressive behaviors when handling peer conflicts (Li & O' Connor, 2019). Short-term high-intensity exercise interventions also demonstrate positive effects. Research has shown that following high-intensity exercise, the experimental group exhibited significantly lower aggression scores than the control group, and this effect persisted in subsequent social conflict simulation tasks (vanderSluys et al., 2024). Numerous studies have consistently shown that both long-term and short-term exercise interventions can inhibit aggressive behavior (Muntaner-Mas, 2022; Harmon-Jones et al., 2022).

The impact of exercise interventions on different forms of aggressive behavior has also been validated. Aggressive behavior is typically categorized into emotional aggression and instrumental aggression (Romero-Martínez et al., 2020). Research indicates that exercise interventions are particularly effective in inhibiting emotional aggression because they can regulate individuals' emotional states to prevent impulsive aggression (Fancourt & Finn, 2019). Muntaner-Mas et al. (2022) also found that after 20 minutes of high-intensity interval training, participants'anxiety and anger levels significantly decreased, and their emotional aggression scores were substantially lower than those of the control group. In contrast, the effects of exercise interventions on instrumental aggression are relatively limited, likely because instrumental aggression depends more on cognitive strategies and motivations, which require additional long-term interventions for improvement (Harmon-Jones et al., 2022).

2.2 Variations in Intervention Effects and Influencing Factors

The effectiveness of exercise interventions as an important means of inhibiting aggressive behavior varies depending on manipulation of variables such as intervention type, exercise form, intensity, and duration.

2.2.1 Intervention Type: Acute vs. Long-term Interventions

Exercise interventions can be divided into acute and long-term interventions based on time span. The short-term effects of acute interventions are suitable for rapid inhibition of emotional aggression, while the sustained effects of long-term interventions focus more on enhancing cognitive control and long-term suppression of instrumental aggression.

Acute interventions are typically used to rapidly alleviate emotional fluctuations and significantly reduce impulsive aggression. Chang et al. (2022) found that acute exercise can quickly reduce cortisol levels, thereby inhibiting individuals' aggressive responses in high-stress situations. In contrast, long-term interventions suppress instrumental aggression by improving cognitive flexibility and behavioral synchronization capabilities (Takayanagi & Onaka, 2021). Additionally, research has found that after long-term aerobic exercise interventions, participants exhibited fewer verbal and physical aggressive behaviors when handling peer conflicts (Li & O' Connor, 2019).

2.2.2 Exercise Form: Individual vs. Team Sports, Competitive vs. Non-competitive

Individual sports positively influence aggressive behavior by improving emotional and cognitive functions. Research shows that individual sports (such as jogging, yoga, and swimming) can enhance emotion regulation capabilities, thereby significantly reducing the probability of aggressive behavior (Deshmukh

et al., 2021). Aerobic exercises like running help participants release endorphins to alleviate negative emotions while reducing stress-related cortisol levels, thus inhibiting aggression caused by emotional dysregulation (Fancourt & Finn, 2019).

In contrast, team sports inhibit aggressive behavior more through social connection and group belonging. Team sports (such as basketball and soccer) establish trust and social connectedness among team members through cooperative tasks and shared goals, which further suppresses internal and external conflicts. Steffens et al. (2014) found that in collectivist cultures, team sport members exhibited higher social responsibility and lower aggression levels. Research has also shown that synchronized behaviors in team sports can further strengthen emotional connections within the team by enhancing oxytocin secretion, thereby inhibiting aggressive behavior (Takayanagi & Onaka, 2021; Sun et al., 2024).

Furthermore, exercise forms can be divided into competitive sports (such as boxing, wrestling) and non-competitive sports (such as yoga, tai chi). Non-competitive sports demonstrate more stable effects in inhibiting aggressive behavior. Non-competitive sports, typically accompanied by relaxation and internal focus experiences, can effectively reduce stress hormone levels and promote emotional awareness and regulation capabilities (Hötting & Röder, 2013). Deshmukh et al. (2021) found that adults participating in yoga training showed significant reductions in both verbal and physical aggression. Non-competitive sports can also maintain lower aggression levels over extended periods by reducing individuals' physiological arousal.

Competitive sports exhibit dual effects in inhibiting aggressive behavior. On one hand, competitive sports can inhibit aggression by releasing suppressed emotions. A study on adolescents found that those who regularly participated in boxing training showed 20% lower aggressive responses than the control group not engaged in competitive sports (Boostani et al., 2012). On the other hand, due to physical contact and high competitiveness, competitive sports may induce higher physiological arousal levels in the short term, thereby increasing the risk of aggressive behavior (Potegal & Nordman, 2023).

2.2.3 Exercise Intensity

The inhibitory effects of high-intensity exercise on aggressive behavior are primarily manifested in rapidly improving individuals' emotion regulation capabilities and reducing impulsive aggression. Goldin et al. (2023) found that high-intensity interval training can significantly enhance participants' cognitive flexibility while reducing their emotional aggression levels in high-stress conflict situations. Research has also shown that high-intensity interval exercise can significantly enhance the functional regulation of amygdala activity by the ventromedial prefrontal cortex, a mechanism that reduces individuals' sensitivity to negative emotions and thereby inhibits aggressive behavior (Weinstein et al., 2012).

However, high-intensity exercise also carries potential risks when emotion regulation is poor or in environments lacking clear rules. Research indicates that high-intensity exercise may induce higher physiological arousal levels in the short term, thereby increasing the risk of emotional aggression (McEwen, 2017). In competitive sports environments, high-intensity physical contact and competition may lead to increased hostility levels (Harmon-Jones et al., 2022).

Moderate- and low-intensity exercises are more suitable for alleviating long-term stress and emotional fluctuations, thereby reducing the negative impact of chronic stress on aggressive behavior. Hötting and Röder (2013) demonstrated that moderate- and low-intensity exercise significantly improved participants' stress tolerance while reducing impulsive aggression triggered by anxiety. Deshmukh et al. (2021) found through yoga training experiments that moderate- and low-intensity yoga practice not only reduced individuals' aggressive verbal and behavioral expressions but also enhanced their emotional stability.

Moderate- and low-intensity exercise also plays a positive role in inhibiting instrumental aggression. Long-term regular moderate- and low-intensity aerobic exercise (such as jogging or swimming) can indirectly inhibit instrumental aggression by enhancing neuroplasticity and cognitive function (Piepmeier & Etnier, 2015).

2.3 Influence of Cultural Background and Individual Characteristics

The effectiveness of exercise interventions is also significantly moderated by cultural background and individual characteristics. In collectivist cultures, group exercise can effectively inhibit aggressive tendencies by enhancing belongingness and social connection. In individualistic cultures, individual exercise is more often viewed as a means of emotion management, helping individuals relieve stress and anxiety, thereby suppressing aggressive behavior (Mazerolle et al., 2020; Cirelli et al., 2021). Against the backdrop of globalization, the cross-cultural migration of exercise forms demonstrates that exercise interventions possess certain cultural adaptability (Smith & Markula, 2018).

Exercise intervention mechanisms and effects also vary significantly across different populations. For adolescents, team sports and low-intensity exercise can significantly inhibit emotional aggression through emotion regulation. Adults, meanwhile, effectively suppress instrumental aggression through high-intensity exercise that enhances cognitive control capabilities (Boostani et al., 2012). Special populations (such as children with autism) exhibit stronger emotional fluctuations and impulsivity, and regular exercise intervention can significantly inhibit their aggressive behavior (Lang et al., 2010). This moderating effect, which varies by culture and population characteristics, further highlights the multidimensional adaptability and potential of exercise interventions in different contexts.

3 Theoretical Explanatory Pathways of Exercise Intervention Inhibiting Aggressive Behavior

Researchers have proposed multiple theoretical explanatory pathways to account for the effects of exercise interventions in inhibiting aggressive behavior, primarily including: emotion regulation theory, cognitive control theory, social connection mechanisms, and social identity pathways.

3.1 Emotion Regulation Theory: Exercise Intervention Inhibits Aggressive Behavior Through Emotion Regulation

Emotion regulation theory represents one of the key theoretical frameworks for understanding how exercise interventions inhibit aggressive behavior. According to this theory, individuals can reduce aggression triggered by emotional dyscontrol through effective emotion management (Gross, 2002), and exercise intervention is considered one of the most effective emotion regulation strategies. Exercise interventions can inhibit aggressive behavior by improving emotional states, relieving stress, and enhancing emotional self-control.

Exercise interventions suppress aggressive behavior by improving emotional states. Research shows that during exercise, the brain secretes endorphins, which act as "happiness factors" that bring pleasurable experiences and alleviate tension (Hötting & Röder, 2013). Additionally, exercise can stimulate dopamine secretion, enhancing individuals' positive emotions and making them more inclined toward cooperative rather than aggressive responses (Humińska-Lisowska, 2024).

Exercise interventions can also inhibit aggressive behavior through stress management. Stress is an important situational factor triggering aggressive behavior, and exercise significantly mitigates the negative impact of stress on emotions by modulating the stress response system (Hamer et al., 2012). Exercise can reduce stress hormone levels, thereby inhibiting impulsive aggression under stress conditions (Milli & Srinivasa, 2022). Furthermore, exercise enhances individuals' frustration tolerance, enabling them to exhibit more rational behavioral responses in conflict situations (Mazerolle et al., 2020).

However, relying solely on the emotion regulation pathway has limitations, particularly when individuals lack cognitive control or group support, making it difficult for emotion regulation effects to sustain. On one hand, emotion regulation cannot completely suppress the impulsive roots of aggressive behavior. Although high-intensity exercise can temporarily alleviate negative emotions, the resulting high physiological arousal may cause individuals to exhibit more aggressive behavior when facing conflicts. On the other hand, for individuals facing strong stressors or deep negative emotion accumulation, a single emotion regulation pathway may be insufficient to form effective behavioral alternative strategies (Tse, 2020). Moreover, emotion regulation theory focuses more on individual internal emotion management and less on interactive processes between individuals and groups.

3.2 Cognitive Control Theory: Exercise Intervention Inhibits Aggressive Behavior Through Cognitive Regulation

Cognitive control theory provides another important perspective for understanding how exercise interventions inhibit aggressive behavior, emphasizing that exercise enhances executive functions, enabling individuals to more effectively manage impulses and emotional responses in high-pressure situations (Diamond, 2013).

Exercise interventions suppress aggressive behavior by enhancing inhibitory control. Inhibitory control, a core component of executive function, refers to individuals' ability to suppress impulses. Research shows that exercise can activate the prefrontal cortex, enhance inhibitory control functions, and thereby suppress impulsive aggressive behavior (Weidler et al., 2020). Vasconcellos et al. (2020) also demonstrated that exercise not only inhibits emotion-driven aggression but also reduces instrumental aggression by suppressing impulses.

Exercise interventions can also inhibit aggressive behavior by improving attention and cognitive flexibility. Aggressive behavior often occurs when individuals cannot flexibly adjust cognitive strategies in complex situations, and exercise interventions provide a cognitive foundation for aggression inhibition by enhancing attention and cognitive flexibility. Research found that individuals who regularly engaged in long-term exercise showed faster reaction times and lower error rates in attention tasks, which was closely associated with significantly reduced aggression in social conflict situations (Sun et al., 2022). An experimental study on adults also showed that participants who engaged in strength training three times per week exhibited significantly reduced aggressive behavior in simulated stress situations, an effect positively correlated with improved cognitive flexibility scores (Romero-Martínez et al., 2022).

Despite providing strong support for exercise interventions, cognitive control theory also exhibits limitations. First, enhancing cognitive control capabilities often requires long-term practice and sustained intervention, and effects may be limited for individuals who cannot develop sufficient neural adaptation in the short term. Second, a single cognitive control mechanism struggles to address emotion-driven aggressive behavior.

3.3 Social Connection: Exercise Intervention Inhibits Aggressive Behavior Through Behavioral Synchronization and Group Belonging

While emotion regulation and cognitive control theories focus on individual exercise interventions, social connection mechanisms provide evidence for how team sports inhibit aggressive behavior.

Team sports enhance social connection through behavioral synchronization and group belonging, which not only reduces hostility among team members but also buffers internal and external group conflicts. Behavioral synchronization, a unique social characteristic of team sports, refers to the temporal and spatial

coordination consistency among team members (Prakash et al., 2024). In team running or group dancing, participants establish emotional resonance and social connection through synchronized movement rhythms (Lopez et al., 2020). Synchronized behavior inhibits hostility-driven aggression by enhancing oxytocin secretion and emotional contagion (Humińska-Lisowska, 2024).

Research has also found that team sports enhance belongingness through cooperative tasks and shared goals, representing another core pathway for inhibiting aggressive behavior (Steffens et al., 2014). Enhanced group belonging not only strengthens trust within the team but also reduces hostility in interactions with out-groups (Vveinhardt & Fominiene et al., 2022).

However, the effects of group belonging are not always positive and exhibit a "double-edged sword" effect. Strong in-group identification may, in some cases, lead to out-group rejection and hostility. Additionally, social connection mechanisms pay less attention to the coordination between individual emotion regulation and cognitive control. In high-stress situations, although behavioral synchronization and belonging among members can temporarily alleviate hostility, without individual-level emotional stability and cognitive regulation capabilities, members may be unable to effectively suppress aggression in actual conflicts.

3.4 Social Identity: Exercise Intervention Inhibits Aggressive Behavior Through Social Identity

Building upon emotion regulation and cognitive control, social identity further enriches the theoretical explanation of how exercise interventions inhibit aggressive behavior. Social identity theory emphasizes that when individuals integrate their identity with group goals, group identification can inhibit hostility between in-groups and out-groups and promote prosocial behavior (Harwood et al., 2020).

Team sports enhance team members' belongingness and identification with the team through cooperative tasks and shared goals, thereby reducing inter-individual conflicts and inhibiting aggressive behavior through internalizing positive group norms. Tsai et al. (2022) found that basketball team members exhibited higher team responsibility and reduced physical conflicts with opponents after teamwork experiences.

Social identity can also influence individual behavioral choices by reinforcing team norms. In environments emphasizing fair competition and cooperation, individuals are more likely to internalize group values and choose non-aggressive coping strategies (Smith & Brown, 2023). A survey study found that participants, due to enhanced responsibility toward their sports team, were more inclined to resolve conflicts through dialogue rather than physical confrontation.

However, in environments lacking clear norms, strong social identity may lead to extreme in-group cohesion and even intensify hostility toward out-groups

(Spaaij & Schaillée, 2019). Although social identity demonstrates significant effects in inhibiting aggressive behavior, its scope and conditions of action remain controversial. First, the intensity of social identity does not always have a linear inhibitory effect on aggression; excessive emphasis on in-group identification may lead to out-group rejection and hostility. Second, different cultural backgrounds may moderate the manifestation of social identity mechanisms. In collectivist cultures, team goals and cooperative tasks may more significantly inhibit aggressive behavior, whereas in individualistic cultures, the role of social identity may be weakened (Richerson et al., 2016; Peterson & Stewart, 2020).

Although emotion regulation, cognitive control, social connection, and social identity mechanisms each reveal pathways through which exercise interventions inhibit aggressive behavior from different perspectives, they do not operate in isolation in practice but rather complement and interact with each other. Emotion regulation can provide a psychologically stable foundation for cognitive control, while cognitive control can further optimize the effects of emotion regulation. Similarly, social connection enhances emotional contagion and emotion regulation capabilities through behavioral synchronization, while social identity reinforces the implementation of cognitive control through group norms. The limitations of single mechanisms further highlight the necessity of comprehensive pathways. Emotion regulation may be unable to independently address complex conflict situations, cognitive control is difficult to execute effectively without emotional stability, and social connection and social identity may even intensify hostility toward out-groups when in-group identification is excessively strengthened. Therefore, to fully understand the inhibitory effects of exercise interventions, proposing an integrated model that combines multiple pathways is particularly important.

3.5 Construction of the Dynamic Interactive Comprehensive Model for Exercise Intervention Inhibiting Aggressive Behavior

We argue that emotion regulation, cognitive control, social connection, and social identity do not operate independently but form a Dynamic Interactive Comprehensive Model through complex interactive relationships. This model integrates the four core pathways of emotion regulation, cognitive control, social connection, and social identity, revealing the complex interactions among them. The model theoretically compensates for the fragmented understanding of exercise intervention mechanisms in previous studies and, for the first time, constructs a panoramic theoretical framework from individual to group levels.

3.5.1 Pathway Interactions at the Individual Level At the individual level, emotion regulation and cognitive control constitute the core psychological pathways that jointly affect individuals' aggressive behavior through bidirectional interactions and lay the foundation for group-level mechanisms.

The facilitating effect of emotion regulation on cognitive control: By reducing negative emotions such as anxiety and anger, emotion regulation provides a

stable psychological foundation for cognitive control. After exercise stabilizes individuals' emotions, their ability to inhibit impulsive behaviors significantly enhances, thereby reducing aggression triggered by impulses (Liu, 2020). Individuals with decreased anxiety levels can better maintain rationality in high-pressure situations, thus avoiding aggressive behavior caused by emotional dyscontrol (McIntyre et al., 2020).

The feedback effect of cognitive control on emotion regulation: Enhanced cognitive control further helps individuals effectively manage emotions when facing conflict situations. After high-intensity exercise interventions, participants can more flexibly adjust their attention focus, thereby avoiding emotional dyscontrol due to external stimuli (Sun et al., 2020). Research has also shown that after high-intensity exercise interventions, participants effectively avoided aggressive behavior triggered by emotional dyscontrol through stronger attention control capabilities (Romero-Martínez et al., 2022).

Furthermore, the bidirectional interaction between emotion regulation and cognitive control is significantly moderated by personal traits and exercise types (Romero-Martínez et al., 2022; Piepmeier & Etnier, 2015).

At the individual level, emotion regulation and cognitive control form a positive feedback cycle through bidirectional interactions, providing a stable foundation for psychology and behavior. This bidirectional interaction not only independently affects individuals' aggressive behavior but also lays the groundwork for the functioning of group-level social connection and social identity mechanisms.

3.5.2 Group-Level Pathways and Mechanism Interactions At the group level, social connection and social identity regulate intra- and inter-group conflicts through synergistic effects, which not only facilitates cooperation and belonging within the group but also reduces out-group conflicts through norm internalization and group cohesion.

The strengthening effect of social connection on social identity: As an important characteristic of group exercise, behavioral synchronization can further enhance social identity by strengthening emotional resonance, thereby achieving the purpose of inhibiting aggressive behavior. Synchronized behavior can also enhance group members' identification with common goals, thereby further strengthening internal group cohesion and effectively inhibiting intra-group conflict behaviors (Ma & Cui, 2022).

The reciprocal effect of social identity on social connection: Strong group identification can motivate individuals to engage more in behavioral synchronization, thereby buffering internal and external group conflicts. In team sports, members improve the frequency and quality of behavioral synchronization through cooperative tasks, while group cohesion and goal identification significantly increase (Richerson et al., 2016).

The bidirectional interaction between social connection and social identity indi-

cates that their relationship forms a positive cycle that continuously enhances intra-group stability and members' belongingness, effectively inhibiting group conflicts. This bidirectional interaction is also influenced by cultural backgrounds (Chang et al., 2020).

In summary, at the group level, social connection and social identity enhance intra-group cooperation and norms through dynamic synergistic effects, inhibiting internal and external group conflicts. Their interaction with individual-level mechanisms jointly influences the inhibition of aggressive behavior.

3.5.3 Interactive Pathways Between Individual and Group Levels
Mechanisms at the individual and group levels interact through complex pathways to jointly affect the inhibition of aggressive behavior. Individuals' improved emotion regulation and cognitive control enable them to more effectively integrate into group activities, while groups' strengthened social connection and social identity further provide supportive environments for individuals, thereby inhibiting aggressive behavior. The specific interactive pathways are as follows:

1. Pathways from Individual to Group

From the individual-to-group interaction perspective, exercise improves individuals' psychological states, leading them to exhibit more cooperative behaviors and lower aggressive tendencies in groups.

Emotion regulation and social connection: When individuals improve emotional stability through exercise, they more easily establish positive emotional connections in team activities. For example, in team basketball, participants with more stable emotions demonstrate higher cooperation willingness and exhibit greater trust and responsibility in intra-group task execution (Harmon-Jones et al., 2022).

Cognitive control and social identity: Enhanced cognitive control capabilities help individuals more flexibly handle conflicts within and outside the group. In team cooperation tasks, participants with higher cognitive control scores demonstrate higher group loyalty and are more inclined to resolve problems through dialogue rather than confrontational behaviors (Vveinhardt & Fominiene, 2022).

2. Pathways from Group to Individual

From the group-to-individual interaction perspective, group mechanisms provide psychological support and behavioral norms for individuals, thereby reducing individual hostility and aggressive behavior.

The facilitating effect of social connection on emotion regulation: Behavioral synchronization in groups significantly enhances individuals' emotional resonance, making it easier for them to manage negative emotions. Research has found that in team running activities, behavioral synchronization significantly reduced participants' anxiety levels (Cirelli et al., 2014).

The supportive effect of social identity on cognitive control: Strong social identity can help individuals enhance self-control capabilities through norm internalization, thereby inhibiting aggressive behavior (Steffens et al., 2014).

In conclusion, individual and group levels form a positive cycle through dynamic interactions: individuals'emotion regulation and cognitive control improve group cooperation and norms, while group support further strengthens individuals'psychological stability and behavioral control. Through this dynamic interactive mechanism, exercise interventions exert synergistic effects across multiple levels, effectively inhibiting not only individual aggressive behavior triggered by impulses but also group aggression by enhancing group cohesion and reducing intra- and inter-group conflicts. The framework of the Dynamic Interactive Comprehensive Model for exercise intervention inhibiting aggressive behavior is detailed in Figure 1 [Figure 1: see original paper].

3.5.4 Functions of the Dynamic Interactive Comprehensive Model

The core function of the Dynamic Interactive Comprehensive Model lies in integrating the four theoretical pathways of emotion regulation, cognitive control, social connection, and social identity to achieve more efficient and adaptive intervention effects through dynamic adjustment mechanisms. On one hand, it constructs a multi-dimensional intervention framework from individual to group levels and from short-term to long-term effects, enabling both rapid emotion regulation through short-term exercise to control acute aggression and sustained enhancement of cognitive functions and social support networks through regular exercise. On the other hand, it dynamically adjusts the interaction weights of each pathway based on intervention contexts, exercise types, and individual characteristics, achieving long-term behavioral pattern reshaping.

4 Neural and Physiological Mechanisms of Exercise Intervention on Aggressive Behavior

To further reveal the underlying mechanisms of exercise interventions in inhibiting aggressive behavior, researchers have increasingly focused on neural and physiological mechanisms. These mechanisms, by modulating neural activity and physiological functions, not only provide biological support for theoretical pathways such as emotion regulation and cognitive control but also play important roles in optimizing social connection and identity. The following sections specifically examine these effects through brain-derived neurotrophic factor (BDNF), oxytocin secretion, neural function regulation, and stress hormones.

4.1 The Facilitating Role of Brain-Derived Neurotrophic Factor

Brain-derived neurotrophic factor is considered a key molecule through which exercise promotes cognitive and emotional regulation. Aerobic exercise, particularly moderate-to-high intensity aerobic exercise, can significantly increase BDNF secretion levels in the brain. This effect not only enhances brain neuro-

plasticity but also improves functional connectivity between the hippocampus and prefrontal cortex, thereby optimizing executive functions. Piepmeier and Etnier (2015) found that a 6-week aerobic exercise intervention significantly improved participants' cognitive performance and substantially inhibited their aggressive responses.

Furthermore, recent research indicates that increased BDNF levels are particularly significant in inhibiting instrumental aggression because they can effectively enhance individuals' planning capabilities and cognitive flexibility (Smith et al., 2023). Therefore, long-term regular exercise interventions provide important neurobiological support for the cognitive control pathway by enhancing BDNF levels.

4.2 Oxytocin Secretion and Strengthening of Social Connection

Oxytocin is widely recognized as the "prosocial hormone" and plays an important role in exercise interventions. Behavioral synchronization in team sports can significantly enhance social connection by increasing oxytocin secretion (Takayanagi & Onaka, 2021). This mechanism reduces intra-group conflict and significantly inhibits out-group hostility by enhancing trust and cooperation among team members.

Additionally, elevated oxytocin levels can reduce emotional activation levels in high-conflict situations by modulating excessive amygdala responses, thereby inhibiting emotional aggression (Wang et al., 2023).

4.3 Regulation of Prefrontal Cortex and Amygdala Function

The prefrontal cortex plays a central role in cognitive control and emotion inhibition, while the amygdala is primarily responsible for generating emotional responses. Exercise interventions can significantly regulate the functional connectivity between these two key regions, providing important neurobiological mechanisms for inhibiting aggressive behavior.

Recent research has revealed the unique role of short-term high-intensity exercise in emotion regulation. A functional magnetic resonance imaging study showed that short-term high-intensity interval exercise can significantly enhance the functional regulation of amygdala activity by the ventromedial prefrontal cortex, a mechanism that reduces individuals' sensitivity to negative emotions (Goldin et al., 2023). By strengthening the connection between the prefrontal cortex and amygdala, individuals exhibit stronger emotion inhibition capabilities in high-stress situations, significantly reducing impulsive aggression triggered by emotional dyscontrol. Short-term aerobic exercise has also been found to rapidly reduce stress hormone levels and enhance individuals' tolerance for negative emotions such as anger and anxiety (Huang et al., 2022).

Long-term regular exercise interventions have greater advantages in optimizing prefrontal cortex function. Research has found that 12 weeks of continuous aer-

obic exercise can significantly increase the volume and function of the prefrontal cortex, a enhancement that plays an important role in inhibiting instrumental aggression (Weinstein et al., 2012).

4.4 The Regulatory Role of Stress Hormones

Cortisol is a core hormone in the stress response, and excessively high levels are typically associated with aggressive behavior. Exercise interventions significantly alleviate individuals' stress responses by reducing cortisol levels. An experimental study on college students showed that after 30 minutes of moderate-intensity running, participants' aggressive responses in simulated conflict tasks significantly decreased, an effect positively correlated with their significantly reduced cortisol levels (Chang et al., 2022).

Regular exercise not only alleviates acute stress responses but also enhances individuals' tolerance to long-term stress by improving hypothalamic-pituitary-adrenal axis function (Hamer, 2012). This mechanism provides an important emotion management tool for individuals working in high-pressure environments over extended periods (such as medical staff or teachers).

In summary, neural and physiological mechanisms provide important neurobiological support for exercise interventions in inhibiting aggressive behavior. By regulating BDNF levels, enhancing oxytocin secretion, optimizing functional connectivity between the prefrontal cortex and amygdala, and reducing stress hormone levels, exercise interventions play important roles across emotion regulation, cognitive control, social connection, and social identity pathways.

5 Research Prospects

Based on existing research, this paper proposes a Dynamic Interactive Comprehensive Model for exercise intervention inhibiting aggressive behavior, revealing the mechanisms through multidimensional pathways including emotion regulation, cognitive control, social connection, and social identity. This theoretical framework not only deepens our understanding of exercise intervention effects but also provides practical guidance for intervention design. However, current research still has limitations, and future studies can be deepened in the following aspects:

First, further validation and optimization of the Dynamic Interactive Comprehensive Model represent an important direction for future research. Future studies can verify the model' s applicability through cross-cultural comparative experiments and explore differences in the contributions of various mechanisms under different cultural backgrounds. By combining neuroscience and behavioral science methods, researchers can monitor real-time changes in neural activity and their associations with aggression improvement, providing more sufficient empirical support for the Dynamic Interactive Model. Additionally, the application of emerging computational technologies offers new opportunities for studying dynamic interactive processes. Future research can employ Dynamic

Causal Modeling (DCM) or time series analysis techniques to separate the dynamic effects of mechanisms such as emotion regulation, cognitive control, social connection, and social identity across different time periods. These technologies can not only quantitatively analyze the contributions of each pathway to aggression inhibition but also reveal the interaction strength and changing trends between mechanisms, providing data support for model optimization. These technologies can also be used to develop intelligent monitoring systems that adjust intervention strategies in real-time based on feedback from intervention objects, thereby achieving personalized exercise program design.

Second, research on the neural and physiological mechanisms of exercise interventions requires further deepening. As discussed in Section 4, key mechanisms including BDNF, oxytocin secretion, prefrontal cortex-amygdala functional connectivity, and stress hormones have been explored. Future research can further reveal the differential manifestations of these mechanisms across different exercise intensities, forms, and cycles. Additionally, by combining real-time neuroimaging and biomarker monitoring technologies, future studies can more precisely reveal the interaction patterns between neural and physiological mechanisms in exercise interventions, thereby providing stronger support for the Dynamic Interactive Comprehensive Model.

Furthermore, future research should focus on optimizing the design of exercise forms and situational variables. Different exercise forms (such as competitive vs. non-competitive sports) influence aggressive behavior through different mechanisms, while intervention effects often vary depending on situational variables. For example, high-intensity exercise may increase impulses in the short term due to excessive arousal, but in contexts with clear rules and cooperative goals, its effects may transform into aggression inhibition. This suggests that future research needs to clarify the specific impacts of situational variables such as rule design, goal orientation, and team culture on intervention effects to optimize the practical application value of intervention protocols.

Finally, future research should design more precise intervention protocols for individuals with high aggression levels. For emotionally sensitive and impulsive individuals, low-intensity exercise (such as yoga or tai chi) can be prioritized to reduce anxiety and anger levels and enhance emotional stability. For individuals exhibiting instrumental aggression based on planning and cognitive strategies, long-term regular aerobic exercise (such as swimming or jogging) is recommended to enhance cognitive flexibility and inhibitory control capabilities. Additionally, the combination of individual and group interventions can further enhance intervention effects.

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