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More Stable Performance: An Analogical Learning Perspective on Motor Skills

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Abstract

Motor skill analogical learning refers to the integration of the overall knowledge and rules of a to-be-learned motor skill into a more comprehensible biological metaphor. The use of analogical learning in motor skill acquisition can enable learners to maintain stable motor performance under pressure, interference, and high-complexity decision-making situations; however, its effectiveness is also influenced by learners' motor proficiency level, instructional content, and cognitive factors. This paper contends that previous research has overemphasized the role of working memory in analogical learning, and proposes an attentional focus-reinvestment-working memory model of motor skill analogical learning, delineating several potential pathways through which attentional focus, reinvestment, and working memory influence the facilitative effects of analogical learning on motor performance. Future research should further investigate three key aspects: the quantity of analogical learning instructions, evaluation criteria for instruction formulation, and the selection of motor tasks, while also exploring the cognitive and neural mechanisms underlying analogical learning.

Full Text

More Stable Performance: A Perspective from Motor Skill Analogy Learning

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Abstract

Motor skill analogy learning integrates the overall knowledge and rules of a motor skill into an easily understood biomechanical metaphor. Using analogy learning during motor skill acquisition enables learners to maintain stable performance under pressure, in distracting environments, and in high-complexity

decision-making situations. However, learning effectiveness is influenced by learners' motor proficiency levels, instruction content, and cognitive factors. This paper argues that previous research has exaggerated the role of working memory in analogy learning and proposes an Attention Focus-Reinvestment-Working Memory Model of motor skill analogy learning, which outlines several possible pathways through which attention focus, reinvestment, and working memory influence the facilitative effects of analogy learning on motor performance. Future research should further investigate three aspects: the number of analogy instructions, evaluation criteria for instruction development, and selection of motor tasks, while also exploring the cognitive and neural mechanisms of analogy learning.

Keywords: analogy learning, motor skill learning, reinvestment theory, attention focus, chunking theory

Introduction

The term “analogy” originates from Greek, meaning “according to ratio,” and refers to the comparison of two similar concepts (柳皓严, 于志华, 2005). Analogy is widely applied in both educational (陈栩茜等, 2012; 刘玉琛等, 2020; 武欣嵘等, 2020) and sports domains (Liao & Masters, 2001; Lola & Tzetzis, 2021; van Duijn, Hoskens, et al., 2019). Its important function is to explain one concept through another—that is, to transform unfamiliar concepts into familiar ones through analogy, thereby helping learners understand new things (Gentner, 1983).

In the sports domain, Masters (2000) proposed a new method for motor skill learning—analogy learning. Motor skill analogy learning involves summarizing the overall knowledge and rules of a motor skill into a single, more easily understood biomechanical metaphor (Liao & Masters, 2001). For example, Liao and Masters (2001) compared the motor performance of analogy learning, implicit learning, and explicit learning in acquiring the table tennis forehand topspin stroke. The explicit learning group received instructions in the form of clear movement rules, the implicit learning group received no instructions, while the analogy learning group was taught using the analogy of “moving the racket as if along the hypotenuse of a right triangle.” The results showed that the analogy and implicit learning groups accumulated fewer explicit rules during the learning phase compared to the explicit learning group. When simultaneously performing a secondary task, the explicit learning group's performance declined significantly, whereas the analogy and implicit learning groups maintained stable performance. These findings indicate that analogy learning possesses characteristics of implicit learning and represents a method of implicit learning. Similar learning effects between analogy and implicit learning have also been supported in balance skill acquisition (Orrell et al., 2006).

Research has found that motor skills acquired through implicit learning remain stable under psychological pressure (Masters, 1992; Liao & Masters, 2001), physiological fatigue (Poolton et al., 2007a), and distracting conditions (Orrell et al.,

2006). Similarly, as a method of implicit learning, analogy learning offers comparable advantages over explicit learning. For instance, under psychological pressure, analogy learning effectively prevents performance decline (胡桂英, 许百华, 2009; Lam et al., 2009; Liao & Masters, 2001). In distracting situations, analogy learning maintains stable performance (胡桂英等, 2016; Poolton et al., 2007b; van Duijn, Hoskens, et al., 2019). In high-complexity decision-making situations, motor skills acquired through analogy learning demonstrate greater stability (Poolton et al., 2006; Masters et al., 2008; Schlapkohl et al., 2012).

Since implicit learning consistently yields lower performance than explicit learning during practice (Maxwell et al., 2000), while analogy learning produces performance equivalent to explicit learning during practice (Liao & Masters, 2001), analogy learning addresses this limitation and enhances the practical applicability of implicit motor learning methods. This provides coaches and teachers with a practical approach for teaching new motor skills.

This paper summarizes the role of analogy in motor skill learning and its influencing factors, analyzes the cognitive mechanisms of analogy in motor skill learning, reviews limitations and controversies in previous research while proposing a new model, and finally discusses future research prospects for analogy in the sports domain.

2.1 Stability Under Pressure Situations

In motor skill learning, motor skills acquired through analogy learning demonstrate more stable performance under pressure. Since Liao and Masters (2001) discovered through a table tennis forehand topspin task that analogy learning is a form of implicit learning and that skills acquired via analogy maintain stable performance under pressure, this effect has been consistently replicated in other sports (胡桂英, 许百华, 2009; Lam et al., 2009; Tse et al., 2013).

Lam et al. (2009) investigated the effectiveness of analogy learning in preventing motor skill performance decline under pressure using a modified seated basketball task. Participants completed two learning phases and one test phase over three days. The results showed no significant differences between the analogy and explicit learning groups during the learning phase. However, under pressure—where participants received monetary rewards for exceeding their previous highest score and incurred losses for failing to reach a certain threshold—the explicit learning group's performance declined while the analogy learning group's performance remained stable. These findings demonstrate that analogy learning can effectively prevent performance deterioration under pressure. Additionally, researchers have found similar advantages for analogy learning groups in other sports such as golf putting (胡桂英, 许百华, 2009; Lam & Masters, 2009), and even in studies examining verbal motor performance like public speaking (Tse et al., 2013).

However, some studies do not support these findings (Schücker et al., 2013). Schücker et al. (2013) employed a golf putting task and found that neither the

analogy nor explicit learning groups showed performance decline under pressure; in fact, performance improved from low-pressure to high-pressure conditions. This suggests that pressure affected both groups similarly and that analogy learning did not demonstrate an advantage in pressure situations, thereby contradicting the view that analogy learning produces superior performance under pressure compared to explicit learning. Nevertheless, Schücker et al.'s study differed from previous research in its pressure manipulation, using a low-high-low pressure testing protocol rather than measuring performance directly under high pressure. The low-pressure condition may have imposed minimal working memory load on both groups, and although the pressure induction from low to high was significant, the change was too small to disrupt participants' motor performance.

Although these studies present inconsistent conclusions, the discrepancies primarily stem from additional factors. Overall, the viewpoint that analogy learning plays an important role in stabilizing performance under pressure receives effective support.

2.2 Stability Under Interference Situations

In real competitions, athletes' performance is often affected by various intentional or unintentional distractions, and analogy learning offers a practical and effective solution to this problem (Liao & Masters, 2001). Researchers have conducted in-depth explorations of this issue (胡桂英等, 2016; Koedijker et al., 2011; Poolton et al., 2007b; van Duijn, Hoskens, et al., 2019).

Poolton et al. (2007b) investigated the effects of analogy and explicit learning on motor performance in distracting situations using a table tennis forehand top-spin task. The results revealed that when the explicit learning group performed a concurrent backward counting task (participants counted down from 1100 by threes), their hitting scores were significantly lower than in the single-task condition (motor task only), whereas the analogy learning group's performance remained stable. Additionally, analogy learning maintained stable performance across various interference task conditions, such as a tone task (listening to a series of six monosyllabic animal names and repeating target words upon hearing them), a digit reversal task (listening to random two-digit numbers and reporting them reversed), and a pitch discrimination task (listening to high and low tones and reporting the high tones) (胡桂英等, 2016; Koedijker et al., 2011; van Duijn, Hoskens, et al., 2019).

Subsequent research on different sports and participant populations has supported this view, with similar findings reported in golf putting tasks (胡桂英等, 2016), hockey push-pass tasks (van Duijn et al., 2019), table tennis tasks with older adults (Tse, Wong, et al., 2017), and rope skipping tasks with children (Tse, Fong, et al., 2017), demonstrating that motor skills acquired through analogy learning exhibit stability in distracting situations.

However, van Duijn et al. (2019) found inconsistent results when investigating

the effects of analogy and explicit learning on children's motor skill acquisition using a golf chipping task. This study employed a within-subjects design where participants received explicit learning followed by analogy learning for the same movement, with performance measured under both conditions. The results showed that under distracting conditions—performing a concurrent tone counting task—neither learning condition led to performance decline. Van Duijn et al. (2019) suggested that this phenomenon might occur because processing numerous explicit rules exceeded children's working memory capacity, thereby disrupting motor performance, so completing a dual task did not substantially change performance.

This paper argues that the primary limitation of this study is its within-subjects design, which cannot rule out the possibility that learners in the analogy condition continued using explicit rules from the explicit learning phase to control their movements, preventing analogy learning from exerting its effect. Additionally, the instructions may not have explicitly required participants to perform both the motor task and secondary task as well as possible simultaneously. Consequently, children may have prioritized motor performance over the secondary task during testing, causing their limited working memory resources to process only the movement instructions and reducing processing of the secondary task, which resulted in no significant performance changes between the two learning groups (van Duijn, Hoskens, et al., 2019).

Although this study did not find an advantage for analogy learning over explicit learning in terms of performance stability, the likely reasons include interference from prior explicit learning on subsequent analogy learning performance in the within-subjects design and a floor effect on working memory cognitive load caused by task difficulty in child participants. Overall, analogy learning consistently maintains stable performance in distracting situations.

2.3 Stability in High-Complexity Decision-Making Situations

In sports competitions, athletes frequently face situations requiring them to make decisions and execute movements within very short timeframes (Poolton et al., 2006). Motor skills acquired through analogy learning enable participants to maintain stable performance in high-complexity decision-making situations (Masters et al., 2008; Poolton et al., 2006; Schlapkohl et al., 2012).

For example, Poolton et al. (2006) used a table tennis forehand topspin task to examine the performance of analogy and explicit learning groups under low- and high-complexity decision-making conditions. In the low-complexity condition, participants hit white balls to the right target area and yellow balls to the left target area. In the high-complexity condition, participants switched the target areas corresponding to ball colors after every two hits—for instance, hitting white balls to the right and yellow balls to the left for the first and second shots, then switching to white balls left and yellow balls right for the third and fourth shots, and so on. The results showed that both groups' performance was unaffected in

the low-complexity condition. However, in the high-complexity condition, the explicit learning group's performance declined while the analogy learning group's performance remained unaffected. Thus, analogy learning serves to maintain performance stability in high-complexity decision-making situations.

Building on this work, Masters et al. (2008) further investigated the performance of analogy learners in complex decision-making situations under time constraints. The results revealed that under time-limited conditions (achieved by shortening the ball-serving interval of the serving machine), explicit learners' performance was affected in high-complexity decision-making but not in low-complexity conditions. In contrast, analogy learners showed no significant differences in motor skill performance between high- and low-complexity decision-making, indicating that analogy learners maintain stable performance even in high-complexity decision-making situations under time constraints.

However, this effect differs between experts and novices. Schlapkohl et al. (2012) found that in high-complexity decision-making situations, novice analogy learning groups performed better, while expert explicit learning groups demonstrated superior performance.

Given the high complexity and time constraints of competitive environments, athletes must frequently make decisions and execute actions within very brief periods. Current research indicates that novice analogy learning groups and expert explicit learning groups show more stable performance in high-complexity decision-making situations. However, studies examining the performance of analogy learners in complex decision-making contexts remain limited and have not been extended to a broader range of sports and populations, requiring further empirical support in future research.

3.1 Motor Proficiency Level

Different motor proficiency levels influence motor skill learning performance under analogy learning conditions. Tielemann et al. (2008) conducted a meta-analysis of 33 independent effects across eight multi-experiment studies comparing analogy and explicit learning, finding that analogy learning had a greater positive effect on motor skill learning, but this advantage existed primarily for novices rather than experts.

Schlapkohl et al. (2012) examined the performance of experts and novices in table tennis forehand topspin strokes. For experts, the explicit learning group outperformed the analogy learning group in post-tests and retention tests. For intermediate-level learners, the explicit learning group showed superior forehand topspin performance in post-tests compared to the analogy group. However, for novices, the analogy learning group demonstrated better hitting performance. Verbal report data revealed that both novice and expert explicit learning groups reported more explicit rules compared to analogy learning groups. Therefore, for experts who have already mastered certain movement rules, knowledge accumulation and problem-solving strategies are more beneficial—they only need

to recall known rules and memorize a few new ones, so the explicit rules in explicit learning do not burden their working memory. For novices, however, explicit learning requires memorizing multiple rules, placing high demands on working memory load, whereas analogy learning can reduce knowledge accumulation, decrease movement memory load, and minimize conscious control, thereby improving motor performance. Capiro et al. (2019) reported similar findings, showing that over time, both analogy and explicit novice groups in softball batting demonstrated significant improvements, while intermediate-level analogy and explicit learners showed no significant batting performance gains.

Although intermediate-level learners did not show significant performance advantages under analogy learning conditions, Meier et al. (2020) used a structural dimensional analysis of mental representation to investigate this population and found that both analogy and explicit learning groups of intermediate-level learners developed more meaningful sets related to functional phases of tennis serves in post-tests and retention tests, indicating functional development of their mental structures. Therefore, novices may be more suited to analogy learning in motor skill acquisition, while experts benefit more from clear, rule-based explicit learning for rapid and long-term learning processes (Schlapkohl et al., 2012), and intermediate-level learners can benefit from both instructional approaches.

3.2 Instruction Content

Instruction content influences motor skill learning performance under analogy learning conditions. First, when learners' needs, knowledge, and prior experiences are not considered, analogy instructions may create problems of multiple interpretations, leading learners to exhibit markedly different movements. For example, Bobrownicki et al. (2019) suggested that in the analogy instruction "move your arm like a catapult," the term "catapult" might evoke two different images—a slingshot and a trebuchet—whose movement patterns are inconsistent, potentially causing learners to develop multiple interpretations of the analogy instruction and negatively impacting their motor skill learning performance. Consequently, differences in coaches' and athletes' experiences and knowledge may lead to inconsistent understanding of analogy instructions, resulting in their ineffective use or misuse.

Furthermore, the impact of analogy instructions on learners' motor performance may vary inconsistently across cultural backgrounds. Liao et al. (2001) used the analogy instruction "move the racket as if along the hypotenuse of a right triangle" for English speakers learning the table tennis forehand topspin stroke, finding that the analogy learning group accumulated fewer explicit rules and demonstrated better stability in dual-task conditions compared to the explicit learning group. However, when Poolton et al. (2007b) translated this instruction into Chinese, they found it ineffective for Chinese speakers. Although learners reported understanding the analogy instruction's content, they experienced difficulty mapping the analogy's principles onto their movements. This may be because literal translation neglected Chinese communication norms, causing the

analogy to convey inappropriate abstract concepts that could not be effectively applied by learners.

Therefore, Poolton et al. (2007b) adapted the analogy instruction for the table tennis forehand topspin stroke to “move the racket as if moving up a hillside” based on Chinese culture. They found that analogy learners accumulated fewer explicit rules and demonstrated more stable performance in dual-task conditions compared to explicit learners. Thus, in cross-cultural research, analogy learning instruction content requires culturally appropriate adaptation to ensure it can be understood by learners and mapped onto their motor learning process.

In summary, analogy learning instruction content must be tailored to learners, taking into account their culture, experiences, and knowledge. This can be achieved by incorporating learners’ understanding into the instruction content to eliminate potential ambiguity or multiple interpretations (Bobrownicki et al., 2019), or by using alternative, more comprehensive information sources to make instruction content as objective as possible (Abraham & Collins, 2011).

3.3 Cognitive Factors

In addition to the two factors mentioned above, learners’ personal preferences and tendencies, such as preference for verbal instruction and tendency for conscious movement control, also influence motor performance under analogy learning conditions. First, van Duijn et al. (2020) found that under analogy learning conditions, learners with high verbal instruction preference showed significantly reduced activity in left temporal language analysis-related brain regions, such as Broca’s area (syntactic processing and language production) and Wernicke’s area (auditory association and language comprehension), while maintaining stable performance. In contrast, learners with low verbal instruction preference showed no significant reduction in language brain region activity and experienced significant performance decline. Therefore, changes in cognition and motor performance during motor skill learning through analogy learning may depend on learners’ information processing capacity, with analogy learning enhancing language processing efficiency in learners with high verbal preference.

Additionally, van Duijn et al. (2019) investigated the influence of conscious movement control tendencies on motor learning under analogy learning conditions. The experiment provided four weeks of golf chipping training to children around 13 years old and assessed learners’ tendencies to consciously monitor and control their movements using the Movement Specific Reinvestment Scale (MSRS). The results revealed that under analogy learning conditions, participants with lower tendencies for conscious movement control achieved higher accuracy in golf chipping, indicating that conscious movement control tendency negatively predicted performance in analogy learning. Therefore, motor skills acquired by children through analogy learning may be influenced by their tendency for conscious movement control, and coaches need to adjust their teaching styles to accommodate individual differences related to conscious processing, thereby

further improving learners' movement performance.

4 Cognitive Mechanisms of Analogy Learning' s Influence on Motor Skill Performance

This paper compares chunking theory and reinvestment theory in explaining the role of analogy in motor skill learning, argues that previous research may have exaggerated the explanatory power of working memory for analogy, and proposes an Attention Focus-Reinvestment-Working Memory Model in which attention focus, reinvestment, and working memory jointly facilitate analogy learning performance. Specifically, analogy learning reduces working memory load through instructional chunking on one hand, and promotes performance stability by using external attention focus to reduce bodily reinvestment on the other hand. Simultaneously, reduced reinvestment decreases working memory resource utilization, further contributing to performance stability.

A common perspective holds that chunking theory operates in analogy-based motor skill learning, where analogy integrates motor skill rules into chunks that enable learners to execute movements automatically, reducing working memory load and freeing up surplus cognitive resources for secondary task processing (Masters & Liao, 2003). Previous research has found that analogy learning accumulates fewer explicit rules related to motor skills that can be verbally described compared to explicit learning, further supporting chunking theory (Liao & Masters, 2001; van Duijn, Hoskens, et al., 2019; van Duijn et al., 2020).

Additionally, under analogy conditions, high-alpha power (10Hz-12Hz) in left temporal language analysis-related brain regions significantly increased (van Duijn, 2019), indicating that verbal analysis processes may be suppressed during motor performance (Kerick et al., 2001). In other words, analogy learning reduces reliance on verbal information processing, thereby enhancing cognitive efficiency. Therefore, analogy learning may maintain stable participant performance in dual-task conditions by reducing cognitive resources required by working memory.

Another perspective is based on the Theory of Reinvestment proposed by Masters et al. (1992). This theory posits that explicit skill rules are "reinvested" into movement, with learners consciously controlling bodily actions through this declarative knowledge, thereby disrupting the entire motor program and causing performance decline. During explicit learning, learners are provided with explicit movement rules and asked to consciously control their actions according to these explicit instructions. In contrast, analogy learning summarizes explicit rules into a concise "biomechanical metaphor," enabling learners to acquire movements without awareness of the explicit rules underlying movement execution. Consequently, less motor rule information is added, maintaining stable performance (Kleynen et al., 2014).

For example, Kim et al. (2020) investigated the effects of analogy learning on adult females' learning of the Y-balance task (maintaining single-leg balance

without touching the floor while extending the other leg as far as possible). Under dual-task conditions (backward counting task), the Y-balance task requires learners to coordinate novel movements. If learners' motor control relies heavily on conscious control (as in explicit groups), balance performance collapses when disrupted by a secondary task. In contrast, the analogy group relies less on conscious control, thus maintaining stable performance. The results showed that explicit learners' Y-balance task performance significantly decreased under dual-task conditions, whereas analogy learners remained robust and reported less explicit knowledge, supporting this theory.

Both chunking theory and reinvestment theory can partially explain the effects of analogy learning on motor skill acquisition. However, this paper contends that previous research may have exaggerated the explanatory role of working memory in analogy learning. This is because conventional studies typically use multiple explicit learning instructions compared against a single analogy instruction in controlled experiments (Cabral et al., 2020; Lee et al., 2018; Tse, Fong, et al., 2017; Tse, Wong, et al., 2017; van Duijn, Thomas, et al., 2019). The different number of instructions itself may lead to varying working memory loads, with the larger number of explicit learning instructions potentially placing greater demands on learners' working memory. Consequently, the observed stability of analogy instruction performance cannot exclude the influence of working memory differences caused by instruction quantity itself. In summary, existing analogy learning research may have overlooked working memory load differences resulting from mismatched instruction quantities between explicit and analogy learning, thereby exaggerating the effects of analogy learning on motor skill acquisition.

This paper argues that analogy learning can enhance motor performance by altering learners' attention focus. For example, Chatzopoulos et al. (2020) compared explicit and analogy learning effects on four movements in preschool children: running, long jump, sprinting, and balancing. Interestingly, the analogy learning group's performance was significantly superior to the explicit learning group only in the balancing task, with no significant differences in the other three motor tasks. Kim et al. (2020) also found that adult females in the analogy learning group performed better in single balance tasks compared to the explicit learning group. In balance tasks, the internal attention focus in explicit learning leads learners to consciously control balance movements according to explicit instructions, disrupting automatic balance control processes (Jackson & Holmes, 2011). Conversely, using external attention focus in analogy learning allows learners to employ more "natural" movements to control balance and maintain stability (Wulf & Lewthwaite, 2016).

Notably, Chatzopoulos et al. (2020) used the same number of instructions across the four motor tasks, largely balancing the working memory effects of analogy instructions, and the four instructions provided to the explicit group did not exceed children's working memory capacity (Buszard et al., 2017). Therefore, performance improvements in the balance task can largely be attributed to

learners' greater tendency to use external attention focus under analogy learning conditions. However, due to different movement characteristics in other tasks, their performance depends less on the stability provided by external attention focus (e.g., running emphasizes speed rather than movement stability), making these benefits less likely to be directly reflected in performance scores and thus often overlooked by researchers.

Furthermore, attention focus can maintain stable motor performance in secondary tasks by altering the reinvestment of explicit rules in movement. Explicit instructions contain extensive explicit knowledge about how various body parts should move, making learners more likely to use internal attention focus to observe and correct their own movements. This increases the amount of explicit rule reinvestment, leading to conscious bodily control that disrupts motor programs, reduces movement automaticity, and compromises skill stability. Simultaneously, increased reinvestment enhances learners' utilization of working memory resources, increasing working memory load and potentially further reducing performance stability (Masters & Maxwell, 2008). In contrast, analogy instructions make learners more likely to use external attention focus, reducing reinvestment of movement rules and thus more easily maintaining performance stability. Additionally, reduced reinvestment decreases working memory load, thereby preserving performance stability.

In summary, this paper proposes the Attention Focus-Reinvestment-Working Memory Model of motor skill analogy learning, suggesting that the cognitive mechanisms through which analogy learning influences motor performance may involve several pathways (as shown in Figure 1 [Figure 1: see original paper]). First, analogy learning integrates motor skill rules into chunks that enable learners to execute movements automatically, reducing working memory load and thereby maintaining performance stability. Second, under analogy conditions, learners are more likely to use external attention focus, which reduces reinvestment of movement rules and enhances performance stability. Additionally, compared to explicit learning, reduced reinvestment decreases working memory load, further promoting performance stability.

Figure 1. Attention Focus-Reinvestment-Working Memory Model of Motor Skill Analogy Learning. Working memory, attention focus, and reinvestment jointly influence the facilitative effects of analogy learning on motor performance. Additionally, under analogy conditions, learners use fewer working memory resources, thereby promoting performance stability, and are more likely to use external attention focus, which reduces reinvestment of movement rules and consequently enhances performance stability. '+' indicates facilitation, '-' indicates reduction.

5.1 Mismatch in Instruction Quantity and Low Ecological Validity of Delivery Methods

As mentioned above, the mismatch in instruction quantity between explicit and analogy learning in analogy learning research may exaggerate the effects

of analogy instructions on motor skill acquisition. Compared to a single analogy instruction, multiple explicit instructions increase working memory load through greater content quantity, making it difficult to attribute performance stability directly to the inherent advantages of analogy learning. To date, most researchers continue to habitually use traditional unequal instruction quantity designs from previous studies, with only some controlling for instruction quantity (Bobrownicki et al., 2019; Meier et al., 2020).

Furthermore, the methods researchers use to provide instructions in analogy learning experiments lack ecological validity. In experimental design, explicit learning instructions are often repeated in full multiple times during the learning phase, which differs from real-world motor skill learning patterns. In Schücker et al.'s (2013) experimental design for golf putting skill learning, a complete set of six explicit learning instructions was repeated every 50 putts, for a total of six repetitions. In real-life situations, learners typically receive step-by-step instruction, where each session provides only one or two instructions rather than repeating all instructions (Tse, Wong, et al., 2017). This suggests that when researchers use traditional experimental paradigms with multiple explicit learning instructions, the repeated and complete presentation of numerous explicit instructions further widens the gap with single analogy instruction, beyond the interference caused by instruction quantity mismatch on working memory and conscious control.

In response, Meier et al. (2020) innovatively improved instruction delivery methods. The study required coaches to develop instructions that corresponded one-to-one with the 11 Basic Action Concepts (BACs) contained in the tennis serve. Basic Action Concepts refer to cognitive chunks of postures and movement events related to common functions for achieving action goals (Schack et al., 2014), encompassing movements of various body parts during different phases of the tennis serve. Coaches and researchers then assessed learners' tennis serve performance in pre-tests to identify which BACs corresponded to each learner's serving errors. Finally, during the motor learning phase, each learner received only the analogy instruction corresponding to that specific BAC rather than instructions for all 11 BACs. This innovative research method reduced repeated instruction presentation, making it more similar to real-world motor skill learning and training scenarios and enhancing the study's external validity.

5.2 Lack of Standardized Procedures for Instruction Development and Effectiveness Evaluation

Previous research typically manipulates analogy learning conditions by providing learners with analogy instructions, necessitating a standardized method for developing analogy instruction content and comprehensive evaluation criteria to ensure the effectiveness of analogy learning manipulations. However, current research remains in the exploratory stage regarding instruction development methods and evaluation standards.

In terms of instruction development, previous studies have primarily used empirical and expert methods to determine analogy instruction content. In recent years, most researchers have employed the empirical method, directly using analogy instructions from previous studies or making simple modifications. For instance, Tse et al. (2017) directly used Poolton et al.'s (2007b) instruction “move your racket as if moving up a hillside” as the analogy instruction for table tennis topspin strokes. Bobrownicki et al. (2019) derived their explicit and analogy instructions from compiling previous sources (Kitsantas & Zimmerman, 2007; Maus, 2000).

However, the empirical method's limitation lies in its inability to quantify the effectiveness of analogy instructions used in previous studies. On one hand, as mentioned above, analogy instruction effectiveness is influenced by experience, knowledge, and culture, making previous instructions potentially unsuitable. On the other hand, analogy instructions used in earlier studies often lack standardized development processes and theoretical foundations, rendering it methodologically unsound to directly use these instructions without re-evaluating their effectiveness.

To avoid the limitations of the empirical method, a few researchers have recently employed the expert method for instruction development. Meier et al. (2020) investigated the effects of analogy instructions on tennis serve skill learning. To ensure the validity of the serve instruction content, they selected experts (five tennis coaches with B/A-level certification and extensive training experience) to develop analogy instruction content for use in their own training sessions, then discussed with researchers to determine analogy instructions for different phases of the tennis serve. This study innovatively conducted pre-testing of analogy instruction content, representing an exploratory attempt at measuring instruction effectiveness. Although the development and testing processes have not yet reached standardized levels, this approach provides important insights for future standardization of analogy instruction development and effectiveness evaluation.

5.3 Large Variations in Motor Task Types

Although numerous studies have examined the role of analogy learning in motor skill acquisition in recent years, the motor skill tasks selected vary considerably across studies, making direct comparisons difficult. While 田麦久 et al. (1998) proposed the event-group training theory for classifying sports based on their characteristics, analogy learning research typically focuses on specific movement actions (e.g., table tennis forehand topspin stroke) rather than entire sport processes (e.g., competitive table tennis matches), and often employs non-competitive individual motor tasks, preventing direct application of event-group training theory for classification.

Therefore, based on motor tasks used in existing research, this paper categorizes them according to task characteristics into: technical actions, accuracy actions,

and coordination actions. Technical actions primarily refer to complex or difficult motor skills that learners must acquire. For example, Masters et al. (2001) used analogy instructions to teach participants the table tennis forehand top-spin stroke, a skill frequently employed by subsequent researchers (Poolton et al., 2007b; Tse, Wong, et al., 2017). Additionally, the scissors-style high jump used by Bobrownicki et al. (2015) represents a typical technical action. Accuracy actions, compared to technical actions like high jump, involve simpler and more uniform movement postures with higher demands on learners' motor control abilities, focusing mainly on serving and throwing actions. Performance is typically measured using accuracy indicators such as serve placement or target hitting. Common serving actions include golf putting (Schücker et al., 2013; Cabral et al., 2020; 胡桂英等, 2016), volleyball serving (Lola & Tzetzis, 2021), badminton serving (Lee et al., 2018), and tennis serving (Meier et al., 2020). Common throwing actions include seated basketball shooting (Lam et al., 2009; van Duijn et al., 2020) and dart throwing (Bobrownicki et al., 2019). Coordination actions, compared to the two types above, emphasize coordinated limb movements and often measure learners' motor coordination using indicators such as limb movement paths, angles, and timing differences. Examples include balance tasks (Orrell et al., 2006), rope skipping (Tse, Fong, et al., 2017), and breaststroke swimming (Komar et al., 2014).

While the diversity of motor tasks facilitates generalization of analogy learning applicability, the different characteristics of each sport—such as required motor control abilities, body parts used (e.g., large muscle movements in seated basketball vs. small muscle movements in dart throwing), task complexity, and difficulty—vary substantially. Consequently, analogy learning may affect different projects differently. For instance, Chatzopoulos et al. (2020) investigated preschool children's performance in running, long jump, sprinting, and balancing, finding that analogy learning only enhanced balance performance compared to explicit learning, with no significant differences in the other three motor tasks. Additionally, since different tasks often involve multiple motor characteristics, controlling for a single characteristic across tasks is challenging. Therefore, the replicability of related research findings and the credibility of conclusions require further investigation.

6 Summary and Outlook

This paper summarized the effects of analogy learning on motor performance in motor skill acquisition under pressure situations, distracting situations, and high-complexity decision-making situations, along with factors influencing analogy learning. It examined the mechanisms of analogy learning from the perspectives of chunking theory and reinvestment theory, and proposed the Attention Focus-Reinvestment-Working Memory Model of motor skill analogy learning. Finally, it discussed limitations and shortcomings of existing research regarding instruction quantity and quality and motor task selection. Although previous research has extensively investigated motor skill learning performance under

analogy learning, several issues warrant deeper exploration.

First, researchers need to emphasize matching instruction quantities and can adopt a step-by-step instruction delivery approach based on this foundation to better align with real training scenarios. Simultaneously, more personalized instruction methods can be implemented according to athletes' skill learning status, thereby reducing working memory load and attentional resource occupation from irrelevant or already-mastered movement instructions and improving experimental design external validity. Additionally, controlling the quantity of explicit instructions can help quantify the impact of analogy learning on working memory capacity required for motor performance.

Second, research should focus on the development process of analogy instructions and evaluation of their effectiveness. Some recent studies have attempted to use the expert method for instruction development. Future research can further draw upon coaches' real-world experiences to develop instructions and conduct testing and revision based on this foundation. Establishing standardized procedures and evaluation methods for analogy instruction development remains an important task in analogy learning research. Additionally, instructions can employ a combined analogy-plus-explicit approach (Tse, Fong, et al., 2017), where analogy instructions (or explicit instructions) are used for core movement skills while other movement instructions remain identical. This approach can effectively match instruction quantities while better examining the effects on core movement skills rather than the entire process.

Third, future research should emphasize the selection of motor task types. On one hand, researchers can employ previously unstudied motor tasks to investigate the general applicability of analogy learning and explore how different motor task characteristics may manifest differently in analogy learning. On the other hand, deeper investigations can be conducted based on previously studied motor tasks. For example, comparing different motor tasks and characteristics can examine how task type and features influence motor skill learning in analogy learning, thereby providing new research perspectives on the cognitive mechanisms of analogy learning.

Finally, although numerous studies have speculated about the internal mechanisms of analogy learning, existing research typically infers these mechanisms solely by measuring changes in motor skill performance after analogy learning under pressure, interference, and high-complexity decision-making situations, lacking genuine investigation of cognitive and neural mechanisms. Future research could begin with motor tasks that allow stable head positioning, such as dart throwing and seated basketball, and use techniques like Electroencephalogram (EEG) and functional near-infrared spectroscopy (fNIRS) to examine brain region activation during analogy learning states, enabling in-depth investigation of the neural mechanisms underlying analogy learning.

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