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Effect of Augmented Feedback on Performance: Past, Present, and Potential Applications for Developing Repeated Sprint Ability

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ABSTRACT

Repeated sprint ability (RSA) is a training modality for athletes participating in team sports, where sprints lasting less than 10 seconds are typical. This review examines the impact of augmented feedback (AugFb) on performance, highlighting its role in motor learning and the mechanisms that underpin its effectiveness. Unlike intrinsic feedback, AugFb positively influences skill execution by enhancing motivation and attentional focus. The findings reveal that the type, timing, and frequency of feedback, whether knowledge of performance (KP) or knowledge of results (KR), are critical for enhancing performance outcomes. Age-related differences significantly affect RSA, with children and adolescents demonstrating faster recovery from repeated sprints than adults, attributed to a greater reliance on oxidative metabolism. The review emphasises the need for targeted training interventions that distinguish between linear sprinting and change of direction (COD) skills crucial for competitive environments. Continued research is vital for refining training programmes and enhancing athletic performance while addressing athletes' unique developmental needs across different age groups.
Keywords: Repeated Sprint Ability, Feedback, change of direction, Sprint

INTRODUCTION

Repeated sprint sequences (<10 seconds), interspersed with brief recoveries (<60 seconds), are common in many team sports (Girard et al, 2011). Consequently, the ability to recover and reproduce performance at a high level in subsequent sprints is a critical physical capacity requirement for athletes engaged in these disciplines and has been termed repeated-sprint ability (RSA; Paulauskas et al., 2018).

Sports coaches face various challenges today, including identifying effective coaching methods (Rezaei et al., 2023). Augmented feedback (AugFb), a coaching method for enhancing athlete and learner performance (Walchli et al., 2016), is provided by an external source, such as a coach or display (Oppici et al., 2021; Corbett et al., 2023). In contrast, intrinsic or internal feedback is naturally available during skill execution (Figure 1). According to Tissera et al. (2022), AugFb can be provided in multiple ways and can positively impact motor performance by enhancing motivation and offering guidance on task execution (Bugnon et al., 2023). The motivational aspect fosters a competitive environment, while its informational property assists learners in improving performance (Bugnon et al., 2023).

A significant consideration is the type of instruction the coach provides and whether it directs the learner's focus of attention externally or internally during practice, which has emerged as a critical mediator of performance and motor skill learning (Eguia, Ng and Wong, 2023). Wulf and Lewthwaite (2016) propose the OPTIMAL (Optimising Performance through Intrinsic Motivation and Attention for Learning) theory of motor learning, whereby increasing intrinsic motivation and an external focus of attention improves performance and learning by strengthening the coupling of goals to actions. While substantial evidence indicates that AugFb can improve sport-specific skills like jumping and various sprint performances (Keller et al., 2014; Weakley et al., 2019), its influence on maximal effort performance during fatigue remains unclear (Bella et al., 2023).

Given that RSA is crucial in team sports, even at junior levels (Sheehan et al., 2022; Ruscello et al., 2016), research in this area is notably lacking. Therefore, this review provides an overview of the current literature on the impact of AugFb on performance, explores the concepts, mechanisms, and age-related differences associated with RSA, and offers recommendations to guide future research.

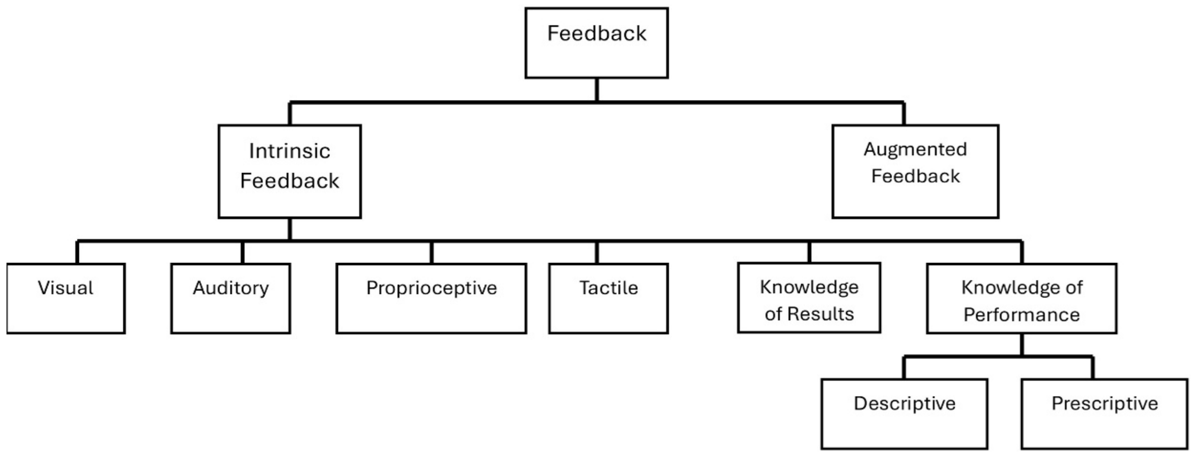

Figure 1. Intrinsic and augmented feedback (Petancevski et al., 2022).

2. Augmented Feedback

The learning effects of AugFb have been extensively examined, focusing on the manipulation of 'what' (type of feedback), 'when' (timing and frequency), and 'how' (modality) feedback is provided during practice (Tissera et al., 2022). For 'what', Nagata et al. (2020) indicate that AugFb can be categorised as either knowledge of performance (KP) or knowledge of results (KR). The 'when' variables consider whether feedback is provided concurrently (during the movement) or terminally (after task completion) and whether it is delivered immediately or with a delay (Corbett et al., 2023; Park et al., 2000). Finally, the 'how' variables encompass the mode of feedback delivery, including verbal, visual, auditory, vibro-tactile, haptic, and multimodal approaches (Petancevski et al., 2022).

2.1 Knowledge of Performance

Knowledge of performance (KP) provides insight into the mechanics of a specific skill, while KR provides information about the outcome of that skill (Petancevski et al., 2022; Nagata et al., 2020). For example, sprint time is a form of KR in sprinting, whereas feedback on sprint technique kinematics, such as stride length, is KP (Doma et al., 2022). Using KP can be beneficial when learning relatively complex skills requiring specific movement techniques for effective execution (Petancevski et al., 2022). KP can be further categorised as descriptive, which describes the execution of movement, or prescriptive, offering guidance on what to do next for improvement, and can also be divided into kinetic (force) or kinematic (movement) information (Oppici et al., 2021). Typically, prescriptive KP is used with beginners to assist and enhance performance, while descriptive KP is more suited for advanced learners who can identify and correct performance errors (Petancevski et al., 2022). A systematic review by Oppici et al. (2021) suggests that combining KR and prescriptive KP is superior for novice populations. However, KP alone may harm performance, as learners may become internally focused, hindering automatic control processes that regulate movement (Wulf, 2013).

2.2 Knowledge of Results

Using KR, which is the simplest form of AugFb (Petancevski et al., 2022), directs a learner toward accurate performance (Lee et al., 1990) and has repeatedly been reported to improve muscular power development and movement speed, including jump distance and sprint times in a range of elite and sub-elite athletes (Bella et al., 2023; Doma et al., 2022). Nagata et al. (2020) suggest that the improvements associated with KR are caused by shifting the focus of attention from internal (e.g., proprioceptive) to external (e.g., jump height/velocity).

2.3 Timing and Frequency

Initially, high-frequency feedback was thought to optimise learning (Chambers and Vickers, 2006). However, the guidance hypothesis (Schmidt et al., 1989) suggests that excessive concurrent feedback can hinder performance by fostering dependency. Learners may focus on intrinsic feedback by reducing feedback frequency, enhancing error detection and correction skills and improving skill retention (Petancevski et al., 2022). Numerous studies have tested the guidance hypothesis by decreasing the frequency of KR. For instance, Park et al. (2000) altered concurrent feedback frequency to assess learning outcomes. Their findings confirmed that 100% concurrent and terminal feedback produced the best acquisition but poorer retention. Similarly, Lee et al. (1990) found that while KR improved performance accuracy, independence from KR led to more consistent performance. Notably, a 50% relative frequency of KR was better for learning than a 100% frequency, suggesting that strong feedback guidance can interfere with developing internal performance mechanisms (Park et al., 2000; Lee et al., 1990).

However, more complex, particularly gross motor and sport-specific skills, can benefit from higher concurrent feedback frequency (Petancevski et al., 2022). Recent studies by Nagata et al. (2020) and Keller et al. (2014) challenge the guidance hypothesis. Keller et al. (2014), comparing varying KR frequencies (100%, 50%, 0%), found that while all KR groups improved short-term jump height, the 100% group achieved the best long-term adaptation - a 14% increase from pre- to post-intervention. Similarly, Nagata et al. (2020) reported that after four weeks of velocity-based training, the 100% KR group exhibited moderate to large effects (ES = 1.02–1.25) in loaded jump squat measures than groups with no AugFb (ES = 0.78–0.82) and 20% KR (ES = 0.74–1.60).

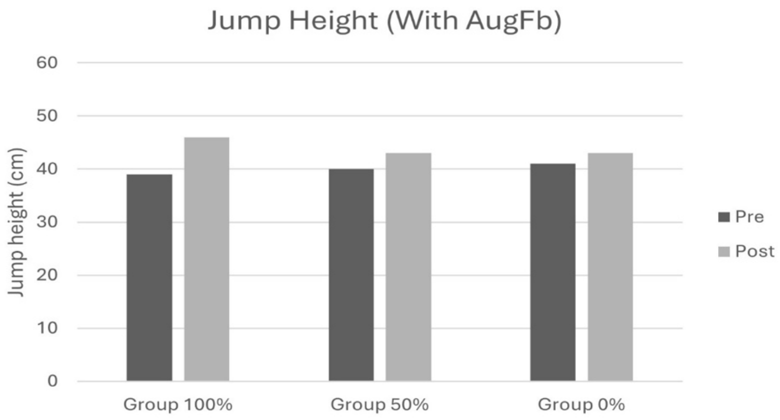

Figure 2. Jump height adaptations in response to training with different frequencies of AugFb (Keller et al., 2014).

While feedback timing and frequency likely depend on task complexity, further investigation into their efficacy in complex motor tasks across various athletic populations is essential. Keller et al. (2014) and Nagata et al. (2020) demonstrate the benefits of frequent AugFb in explosive jumping, but exploring its impact on other performance outcomes is necessary. Such research could inform tailored training strategies for enhancing skill acquisition and overall athletic performance.

2.4 Bandwidth

A frequently used form of AugFb is bandwidth feedback, which delivers KR or KP within a specified accuracy threshold relative to a performance goal (Shimony et al., 2020). Research suggests bandwidth feedback can enhance performance by supplying error feedback only when meaningful corrections are possible (Yabuki et al., 2022). Consequently, bandwidth feedback is considered an effective strategy in alignment with the guidance hypothesis (Lee et al., 1990).

Shimony et al. (2020) examined the effects of wide bandwidth knowledge of results (WBWKR) versus narrow bandwidth knowledge of results (NBWKR) on throwing accuracy and consistency in goalball players with visual impairments. Their findings showed that WBWKR participants achieved more target hits and smaller absolute errors in transfer tests than those receiving NBWKR. Conversely, Yabuki et al. (2022) compared narrow, wide, and adjusted bandwidth KR in a simple grasping force task but reported no significant performance improvement among the bandwidth KR groups relative to the control group. In addition, Sadowski et al. (2013), investigating the impact of two feedback frequencies of KP while participants learned a complex gymnastic skill, argue that overly precise feedback in learning complex motor skills can be as ineffective as vague feedback, as excessive precision can overwhelm learners who can only process a limited amount of information at once. Group 1 received bandwidth feedback, focusing on key movement errors, while Group 2 received 100% feedback on all errors. Performance was evaluated based on technical compliance, revealing that the bandwidth group outperformed the 100% feedback group, likely because they received significantly less error information.

These findings highlight the complex role of bandwidth feedback in skill acquisition and the requirement for further research on its effectiveness across various motor tasks and skill levels. While Shimony et al. (2020) and Sadowski et al. (2013) demonstrate its benefits for elite athletes, the variability in methods and outcomes indicates a need for broader exploration. Examining its efficacy across diverse demographics and skill levels in complex tasks may provide valuable insight for enhancing training methodologies and improving performance.

2.5 Modality

The 'specificity of learning hypothesis' posits that the most effective source of sensory information for performing a movement is specific to the task (Proteau et al., 1998). Building on this concept, Jaszczur-Nowicki et al. (2021) emphasise that feedback must be simple, clear, and concise to enhance athletes' understanding and skill development in motor tasks.

Jaszczur-Nowicki et al. (2021) assessed the effectiveness of different feedback modalities on motor learning of complex tasks by comparing visual feedback on task performance (VIS), verbal feedback about errors (VER), and a combination of verbal and visual feedback (VERVIS) on vertical jump performance. The jumping performance was evaluated by three judges on a scale of 1 to 10. The results revealed significantly higher scores for the VERVIS group than the VER and VIS groups, with improvements of 9% ($p < 0.01$) and 15% ($p < 0.001$), respectively.

The benefits of multimodal AugFb are also supported by Sigrist et al. (2015), confirming that distributing information across different modalities may facilitate increased cognitive processing as individuals use distinct cognitive resources for different types of information. They examined the effectiveness of multimodal audiovisual and visuo-haptic feedback in a rowing simulator for simulating realistic task conditions. While both multimodal feedback types reduced spatial and velocity errors during retention tests, visual feedback alone was already somewhat effective. Consequently, the advantages of adding sonification or haptic feedback were minimal.

These findings highlight the importance of clear and specific feedback in motor learning. However, the most effective modality remains uncertain, particularly since studies have focused on novice populations, raising questions about how elite athletes, who may process information differently, would respond to similar strategies. Therefore, future research should determine the contexts and limitations of different feedback modes across skill levels to create tailored and effective training interventions in athletic settings.

3. Attentional Focus

Attentional focus has emerged as an important mediator of performance and learning across several motor skills (Winkelman et al., 2017). The constrained action hypothesis proposes that an external focus enhances automatic movement control while an internal focus disrupts these control processes (Wulf, 2013). An external attentional focus can expedite learning, improving immediate performance and skill retention (Winkelman et al., 2017). Additionally, the automaticity conferred by an external focus promotes more efficient and economical movement, potentially increasing performance resilience under pressure (Wulf, 2013).

Lohse et al. (2010) reported that an external focus of attention improves movement economy by reducing agonist and antagonist muscle activity in dart throwing. Similarly, Halperin et al. (2016) found that 18 trained athletes generated 9% more force during an isometric midthigh pull with an external than an internal focus ($p < 0.001$) and 5% more force than with control instructions ($p = 0.001$). There was also a significant 3% advantage for external focus over control instructions ($p = 0.03$).

In a more complex motor task, Becker and Smith (2015) examined how attentional focus affects standing long jump performance, showing that the external focus group (198.09cm) jumped significantly better than both the broad (173.74cm, $p = 0.010$) and narrow internal focus groups (178.53cm, $p = 0.049$) (Figure 3). Winkelman et al. (2017) assessed the impact of attentional focus on 10-meter sprint times in collegiate soccer players and highly experienced sprinters. They confirmed that external focus and control conditions for the collegiate players led to significantly faster sprint times than the internal focus condition, although no significant differences existed between the external focus and control groups. Conversely, the experienced sprinters showed no significant differences across any conditions, indicating that experience level influences the effectiveness of attentional focus.

These findings underpin the increasing evidence surrounding attentional focus and highlight the importance of tailoring coaching strategies to an individual's experience level. Further research into the neurophysiological mechanisms involved may provide valuable insights into the cognitive processes related to external versus internal focus in complex motor skills.

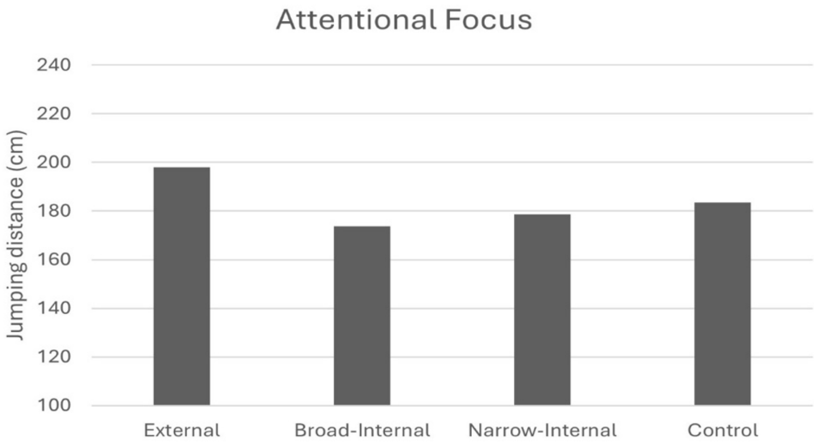

Figure 3. Mean jumping distances and SD for external, broad-internal, narrow internal and control conditions (Becker and Smith, 2015).

4. Motivation

In addition to enhancing performance, feedback significantly influences psychological processes, particularly motivation, during strength and conditioning exercises (Dallaway et al., 2022). Motivation encompasses several contributing factors that affect behaviour's, energisation, direction, and intensity (Wulf and Lewthwaite, 2016) and is typically categorised into intrinsic and extrinsic categories (Walchli et al., 2016). Augmented feedback is an intrinsic mechanism that motivates participants to surpass their previous or maximal performance (Bella et al., 2023).

Walchli et al. (2016) examined the effects of combining various performance enhancement strategies, which included AugFb (intrinsic motivation), momentary reward (extrinsic motivation), and an external focus of attention on jump performance. Their findings indicated that a combination of AugFb and external focus yielded the best results. Additionally, Bugnon et al. (2023) employed both correct and incorrect AugFb to show that, in tasks of lower complexity, the motivational benefits of AugFb predominate, while the informational component plays a more crucial role in complex maximal tasks.

Self-Determination Theory (SDT) provides a framework for understanding the conditions and processes that enhance motivation (Gagné and Deci, 2005). According to SDT, individuals are more likely to experience positive psychological states when autonomously motivated and competent (García et al., 2019). Wulf and Lewthwaite (2016) explain that positive feedback has been shown to enhance perceived competence and alleviate performance anxiety. Conversely, negative feedback can diminish self-esteem, evoke negative emotions, and adversely affect future performance (Motro et al., 2021). In sports performance, phenomena such as choking under pressure or achieving flow states can be intricately linked to an athlete's mental state (Wulf and Lewthwaite, 2016).

García et al. (2019) investigated the effects of positive, negative, and zero feedback on psychological variables and handball throwing performance. Their results show that participants receiving positive feedback before the throwing task displayed significantly higher levels of perceived competence ($p < .001$) and autonomous motivation ($p < .05$) than those receiving negative feedback or no feedback. Furthermore, athletes who received positive feedback demonstrated increased throwing speed at the end of the task compared to both the negative feedback group ($p < 0.001$) and the no-feedback group ($p < .05$).

Moreover, Bella et al. (2023) explored the impact of various feedback modalities on sprint performance, motivation, and mood states in highly trained female rugby league players. Compared to a control group, they revealed heightened motivational states and enjoyment across all feedback conditions, including KR and KP. Interestingly, while KR significantly enhanced linear and curved agility sprints versus KP or control, no significant differences were observed between conditions for RSA.

Motivational Intensity Theory suggests that task performance depends on perceived exertion and motivation, with task termination occurring when the effort required aligns with the maximum exertion an individual is willing to provide (Richter, 2013). Consequently, the motivational benefits of AugFb may diminish during exercise, which requires maximal effort while fatigued (Dallaway et al. , 2022; Bella et al., 2023).

While these insights underpin the positive effects of AugFb on performance and perceived competence, their applicability to individuals with lower mental resilience remains uncertain, as most studies focus on athletic populations. Examining the interaction between fatigue and AugFb in high-stakes situations could yield practical guidelines for coaches and athletes to enhance training outcomes.

5. Repeated Sprint Ability

Repeated sprint ability is critical in high-intensity intermittent sports (Gabbett, 2010). Time-motion analyses within team sports indicate that sprinting typically constitutes 1–10% of the total distance covered and 1–3% of the effective playing time (Girard et al., 2011). Schimpchen et al. (2016) emphasise the significance of RSA by noting that games can be won or lost in pivotal moments that demand repeated sprinting, highlighting the necessity for athletes to effectively maintain high-performance levels whilst resisting fatigue during these efforts.

5.1 Repeated Sprint Protocols

To assess and enhance RSA, a variety of testing protocols have been established, primarily involving unidirectional sprints over distances of 15 to 40 meters, usually comprising 3 to 15 repetitions with recovery periods ranging from 15 to 30 seconds (Selmi et al., 2016; Schimpchen et al., 2016). These RSA tests have a very large to nearly perfect test-retest reliability and discriminate validity of playing position, competitive level, and season phase (Lopes-Silva et al., 2019). Notably, RSA is critical even at junior levels of competition (Ruscello et al., 2016). According to La Monica et al. (2016), the RSA protocol should be representative of the work-to-rest ratio in line with that required in the competitive environment. Commonly used protocols for team sports adopt a work-to-rest ratio of 1:4 or 1:5, signifying 4 to 5 seconds of passive recovery for every second of exertion. (Ruscello et al., 2016). These methods allow athletes to sustain a specific performance level within the speed domain, even as fatigue progressively sets in due to repeated maximal efforts (Ruscello et al., 2016).

5.2 Repeated Sprints with Change of Direction

It is essential to replicate game-specific demands in repeated sprint (RS) protocols to ensure the relevance of testing and the effectiveness of training. Consequently, in recent years, there has been an increased focus on integrating change of direction (COD) into RSA tests and training drills (Buchheit et al., 2012). Change of direction is a critical component of agility, characterised as a pre-planned movement where an athlete does not need to react immediately to a stimulus (Young et al., 2001). This skill is essential for effective performance in most team sports, where participants frequently must change direction while sprinting (Brughelli et al., 2008). Given that COD occurs repeatedly during competition, repeated sprints with COD may be a vital fitness component for athletes involved in team sports (Wong et al., 2012).

5.3 Linear vs. Change of Direction

Compared to linear sprinting, the demands on the neuromuscular system during COD tasks are increased as each COD requires a braking force followed by a propulsive force, increasing the importance of eccentric-concentric force capabilities (Brughelli et al., 2008). Furthermore, the shared variance between linear sprinting abilities and COD performance is less than 50% (Brughelli et al., 2008), suggesting that these two physical qualities are distinct, with transfer benefits diminishing as the complexity of agility tasks increases (Young et al., 2001).

In their investigation of the effects of linear sprint training on agility performance and vice versa, Young et al. (2001) found that after six weeks of training, linear sprint training significantly improved straight-line speed ($p < 0.05$) but did not enhance COD performance. Conversely, agility training yielded significant improvements in COD ($p < 0.05$) without producing substantial gains in linear sprint performance.

However, Buchheit et al. (2012) suggest that RSA, which includes COD, may represent a broader physical quality as besides the initial sprint, the ability to repeat maximal sprints is more closely related to metabolic factors. Wong et al. (2012) examined the relationship between RSA and repeated COD, matched for intervals and distance. Their results showed strong correlations for fastest time, average time, and total time, indicating similar metabolic demands, although the shared variance remained between 48% and 50%, leading the authors to conclude that these abilities are distinct.

These findings highlight the interplay between linear sprinting, COD, and RSA, suggesting that training protocols should be tailored to specific outcomes. However, the predominance of male subjects in current studies limits generalisability. Additionally, Wong et al. (2012) only examined one COD angle, suggesting a need for future research to explore the relationships between RSA and repeated COD across various angles and protocols to better represent different sporting scenarios.

5.4 Performance Measures

Various formulas have been employed to quantitatively assess an athlete's fatigue resistance during RS (Girard et al., 2011). Glaister et al. (2008) identified the percentage decrement calculation as the most valid and reliable method after evaluating eight approaches to quantifying fatigue in multiple-sprint performance tests. In addition to assessing fatigue rates, it is essential to consider performance metrics such as initial sprint speed and total sprint time, which are critical for effectively evaluating RSA (Girard et al., 2011).

6. Physiological Factors

During RS exercise, fatigue manifests as a reduction in maximal sprint speed (e.g., running) or a decrease in peak power output (e.g., cycling), primarily due to failures in central and peripheral mechanisms (Tomazin et al., 2017). Given that recovery times during RS exercise are typically less than 60 seconds, the depletion of phosphocreatine (PCr) stores, coupled with intramuscular acidosis, significantly impairs performance (Girard et al., 2011). However, additional factors, such as reduced neural drive, decreased muscle-tendon unit stiffness, and selective fatigue of fast-twitch muscle fibres, which play a crucial role in power production during supramaximal exercise, may also contribute to performance decrements (Girard et al., 2011; Slawinski et al., 2008; Mendez-Villanueva et al., 2008).

The initial sprint in RS exercise relies on anaerobic metabolism (including adenosine triphosphate, phosphocreatine, and glycolysis), with these contributions gradually diminishing as aerobic metabolism becomes more prominent during subsequent sprints (Wong et al., 2012). Mendez-Villanueva et al. (2008) conducted a repeated cycling sprint test (10 x 6-second max sprints with 30 seconds of rest) and found that across 10 sprints, peak power output and mean power output decreased by 24.1% ($p < 0.001$) and 27.7% ($p < 0.001$) from initial values, respectively (Figure 4).

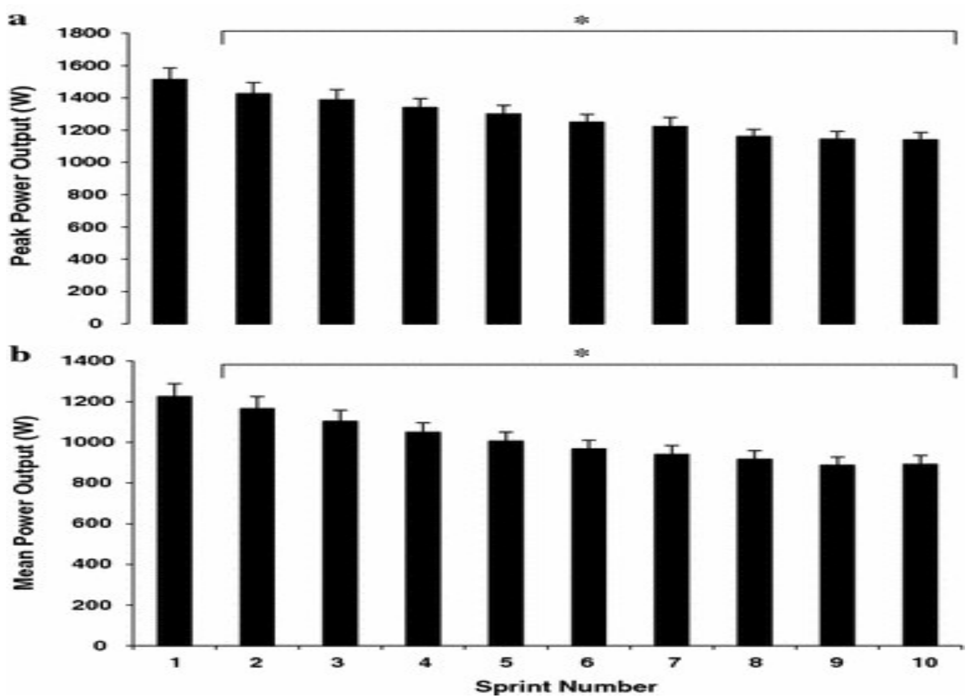

Figure 4. Group mean peak power output (a) and group mean power output (b) across ten sprints (Mendez-Villanueva et al., 2008).

6.1 Initial Sprint Performance

According to the force-fatigability relationship, the greater the force exerted by a muscle or motor unit during a given task, the higher the muscle fatigue (Mendez-Villanueva et al., 2008). Therefore, an athlete achieving a faster initial sprint is expected to exhibit a greater fatigue index (Enoka and Stuart, 1992). Mendez-Villanueva et al. (2008) tested eight healthy males in a repeated cycling sprint protocol and found a significant correlation between anaerobic power reserve (APR) and fatigue index ($R = 0.87$; $p < 0.05$) (Figure 5). Specifically, APR, or anaerobic speed reserve (ASR) in running, are measured as the difference between maximal aerobic power/speed and maximal anaerobic power/sprint speed (Mendez-Villanueva et al., 2008; Sandford et al., 2019). These findings suggest that a lower APR and ASR and increased reliance on aerobic metabolism can enhance RSA performance.

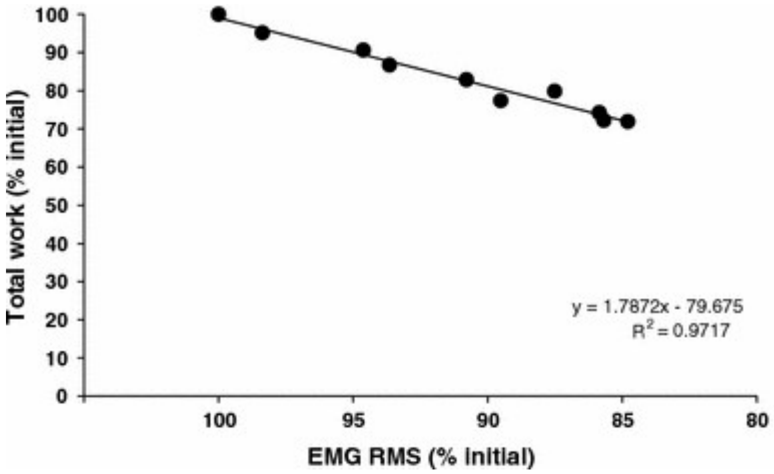

Figure 5. Relationship between total work during sprints 1–10 and vastus lateralis muscle EMG amplitude during the repeated-sprint exercise (Mendez-Villanueva et al., 2008).

6.2 Aerobic Fitness

The significance of aerobic power in RSA is supported by physiological principles and strong correlational data (Thébault et al., 2011). Consequently, many athletes, coaches, and sports scientists maintain that a high level of aerobic fitness, as measured by VO2 max, is crucial for optimal RSA (Bishop and Spencer, 2004). However, Bishop et al. (2003) found no significant correlations between VO2max and total work ($r = 0.35$) or power decrement ($r = 0.30$) in elite female field hockey players during a cycling protocol involving five 6-second all-out sprints with 30 seconds of rest between sprints. Interestingly, they observed a significant correlation between power decrement and changes in plasma hydrogen ions [H+] ($r = 0.66$; $p < 0.05$).

In a related study, Bishop and Spencer (2004) compared RSA and physiological responses between female team sport athletes and endurance athletes while matching them for VO2 max and body mass (54.8 vs 56.1 ml·kg−1·min−1; 60.8 vs 59 kg). Despite matching, team sport athletes demonstrated higher peak power during their initial sprint (16.3 vs 13.6 W/kg), performed increased total work (344.8 vs 298.1 J/kg), and exhibited a significant decrease in power (8.5 vs 5.4%) (Figure 6). These findings imply that the perceived superior RSA in endurance athletes may be more strongly associated with their lower initial sprint performance than their higher VO2 max (Bishop and Edge, 2006). Given these observations, Bishop and Edge (2006) further explored the relationship between VO2max and RSA while controlling for initial sprint performance. They matched two groups of female recreational team sport athletes with varying aerobic fitness levels (VO2 max: 36.4 vs 49.6 ml·kg−1·min−1) on a single 6-second sprint performance. The key finding was that the group with the higher VO2 max had a smaller work decrement over five sprints (11.1 vs. 7.6; $p = 0.045$) and completed significantly more work in the final sprint (Figure 7). Thébault et al. (2011) reinforced these findings, showing that athletes with a maximal aerobic speed (MAS) over 17 km/h demonstrated better fatigue resistance, indicating that those with an MAS of at least 17 km/h or a VO2max of at least 60 ml·kg−1·min−1 can better capitalize on their aerobic fitness.

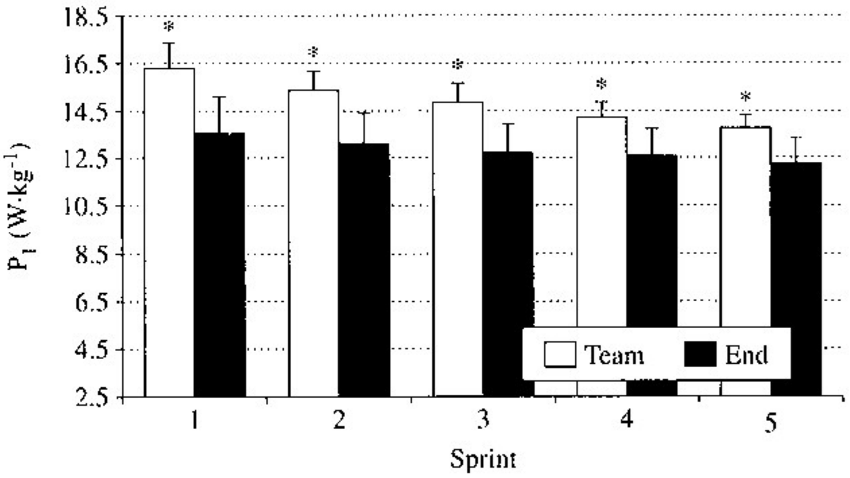

Figure 6. Relative peak power output (PP: W·kg⁻¹) during 5 6-s all-out sprints with 24-s recovery periods for both team sport (Team) and endurance-trained athletes (End) (Bishop and Spencer, 2004).

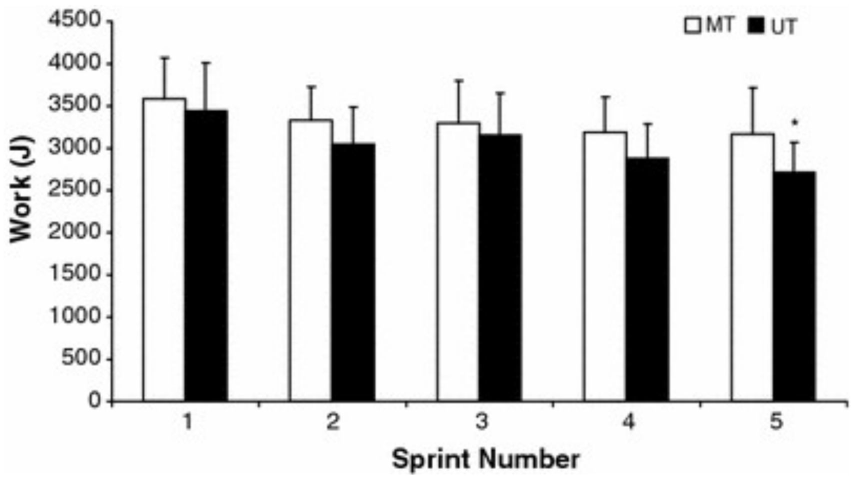

Figure 7. Work (J) during 5, 6-s all-out sprints with 24-s recovery periods for both the untrained (UT) and moderately trained female subjects (MT) (Bishop and Edge, 2006).

In summary, RSA is shaped by various physiological mechanisms, including central and peripheral fatigue, energy contributions, and muscle fiber characteristics. It is important to highlight that most studies have concentrated on cycling protocols, limiting the applicability of their findings to other exercise modalities. Nonetheless, the relationships between anaerobic power and aerobic fitness emphasize the need for tailored training regimes. Athletes should adopt a comprehensive approach that combines sprint-specific and endurance training to enhance RSA.

6.3 Age-related differences

Sprint running performance in children and adolescents depends on several factors mediated by growth and maturation (Mendez-Villanueva et al., 2011), and while it may be true that single sprint performance improves with age, recovery from RS exercise offers a reciprocal relationship (Mujika et al., 2009). Children and adolescents recover faster from RS exercise than adults due to their greater reliance on oxidative metabolism and a faster rate of PCr resynthesis (Mujika et al., 2009). However, it could be argued that as children possess lower anaerobic power compared to adults they have less to recover from (Falk and Dotan, 2006). Empirical evidence supports this notion, as Kappenstein et al. (2015) revealed that blood lactate was significantly lower (5.21 vs. 10.35 mmol·L) and pH significantly higher (7.37 vs. 7.27) after a comparable RSA protocol for children and adults, respectively.

During adolescence, growth rates increase significantly, peaking at around 14 years in boys, followed by a gradual decline until adult stature is achieved (Spencer et al., 2011; Mujika et al., 2009). This period is marked by increased serum testosterone levels, leading to gains in stature, body mass, and muscular development, which contribute to improved functional performance (Waldron et al., 2014). Mujika et al. (2009) examined age-related differences in RSA and blood lactate responses among 134 male youth football players. Their findings showed that the total time for a 6 x 30-meter RSA test improved progressively from the U-11 to U-15 age groups (33.15 vs. 27.25 seconds), with no significant improvements noted from U-15 to U-18. Interestingly, they reported no notable differences in percent sprint decrement across age groups, but post-test peak lactate levels increased with age (ranging from 7.3 to 12.6 mmol).

Similarly, Mendez-Villanueva et al. (2011) investigated high-speed running qualities, including RSA, in 61 highly trained young male soccer players across the U-14, U-16, and U-18 categories. Their results demonstrated strong positive correlations between acceleration, maximum running speed, and RSA ($r = 0.55 – 0.96$) regardless of age group, indicating that these qualities may share common factors in highly trained young males. As anticipated, Mendez-Villanueva et al. (2011) also found significant age-related differences in absolute performance in all sprint-running qualities (Under 18 > Under 16 > Under 14; $p < 0.001$). Furthermore, they observed a weaker correlation between maximum running speed and mean RS time in the U-18 group compared to the U-14 and U-16 groups. This difference may indicate a physiological shift toward a higher relative percentage of type II (fast-twitch) muscle fibres during later adolescence (Bishop and Spencer, 2004; Mujika et al., 2009).

The information offers valuable insights into sprint performance and recovery across various age groups. While comprehensive, it should consider individual variability in maturation and the emphasis on specific sports, as this may limit applicability. Expanding research to encompass a broader range of activities and athlete profiles would enhance the understanding of physiological changes during adolescence and adulthood.

7. Limitations of Current Research

Current research on AugFb reveals several limitations that hinder its application across diverse athletic populations. Several studies focus primarily on specific sports or skill levels (Bella et al., 2023; Doma et al., 2022), which restricts the generalizability of their findings. While differences between KP and KR have been well established (Petancevski et al., 2022), individual learning preferences are often neglected. The guidance hypothesis presents conflicting evidence regarding optimal feedback timing and frequency (Park et al., 2000; Keller et al., 2014). Additionally, research on bandwidth feedback is inconsistent, with studies indicating positive effects while others report minimal impact (Shimony et al., 2020; Yabuki et al., 2022). These variations may arise from differences in experimental design, sample sizes, or task demands, indicating a need for standardization in study designs. Furthermore, the effectiveness of multimodal feedback compared to unimodal feedback remains unclear (Sigrist et al., 2015), pointing to a lack of consensus and rigorous comparative studies to shape best practices for skill acquisition.

Research on attentional focus and motivation acknowledges important findings but highlights limitations, particularly concerning variability in experience levels (Winkelman et al., 2017), complicating generalizations. The lack of diverse participant demographics restricts the application to broader athletic populations. Although motivational theories enhance our understanding, the complexities of intrinsic versus extrinsic motivation concerning attentional focus remain underexplored. Furthermore, numerous studies concentrate on distinct task performances (García et al., 2019) that may not effectively transfer to more dynamic sporting environments, and the interaction between fatigue, attentional focus, and motivation during maximal effort performance is still inadequately researched.

In RSA, limitations stem from excessive dependence on controlled testing protocols that might not truly reflect the real-game demands characterized by frequent COD. While current studies underscore the importance of integrating COD into RSA assessments (Wong et al., 2012), standardized protocols that reflect these realities are absent. Inconsistencies in the literature regarding the role of aerobic fitness in RSA performance (Bishop and Spencer, 2004; Thébault et al., 2011) further highlight the need for multi-faceted approaches that consider a wider array of physiological assessments and performance contexts.

Research into sprint performance among children and adolescents is limited, primarily due to a lack of longitudinal studies that track individual athletes over time. While evidence suggests that children recover faster from RSA exercises due to a reliance on oxidative metabolism (Mujika et al., 2009), this relationship does not fully capture ageing performance discrepancies. The role of hormonal changes during adolescence in physical performance requires deeper exploration, particularly concerning muscle fibre composition. Lastly, addressing the gaps in research on the long-term impacts of AugFb on physiological variables related to RSA is critical for enhancing performance in team sports, especially for developing athletes.

8. Recommendations for Future Research

Future studies should prioritise several critical areas related to AugFb and its impact on performance to address research gaps and enhance our understanding of performance optimization in team sports. First, investigating the effects of different types of AugFb on maximal effort performance under fatigue is essential, particularly among youth athletes. This exploration should also consider age-related differences to develop targeted feedback strategies that enhance skill development and competitive opportunities.

A detailed analysis of the guidance hypothesis is warranted, focusing on the timing and frequency of feedback while accommodating the unique developmental needs of athletes. Additionally, given the insights from Bella et al. (2023) regarding the influence of KR on motivation and performance, future studies should consider how different feedback modalities, such as KR and KP, can be optimized to foster a competitive atmosphere during high-intensity training.

For RSA, incorporating COD within RSA protocols will allow for a more accurate assessment of AugFb in realistic game scenarios, ensuring training specificity. Expanding the ecological validity of testing protocols is vital, emphasizing the need for standardized assessments that include unidirectional and COD sprints to reflect real-game demands.

Longitudinal studies should evaluate the long-term effects of AugFb on RSA and physiological adaptations, tracking athletes' development over time while focusing on how physiological factors like hormonal changes and muscle fiber composition influence sprint performance. Additionally, diversifying research populations to encompass a broader range of team sports and athlete demographics will enhance the generalizability of findings, contributing to the development of tailored training strategies that address individual learning preferences. By pursuing these recommendations, future research can significantly improve the understanding of feedback mechanisms and their role in enhancing RSA and overall motor performance in team sports, ultimately supporting the development of evidence-based practices for athletes at all levels.

Key Insights

1. Impact of feedback: The effectiveness of AugFb hinges on its type, timing, frequency, and modality. Tailoring feedback to the learner's skill level and task complexity can enhance performance and retention.

2. Balanced feedback approach: While frequent feedback can boost immediate performance, it may lead to dependency. A balanced approach, like bandwidth feedback, encourages long-term learning by fostering internal error detection.

3. Performance and motivation: An external focus enhances motor performance by promoting automatic control, while positive AugFb increases athletes' perceived competence and motivation, aiding mental state management during training.

4. Repeated sprint ability: Repeated sprint ability is crucial in high-intensity sports, necessitating sport-specific testing and training protocols. Distinct regimens for linear sprinting and COD are essential for enhancing performance.

5. Multifactorial fatigue: Fatigue in repeated sprints results from phosphocreatine depletion and reduced neural drive, underlining the need for targeted training and recovery strategies to enhance RSA.

6. Age-related recovery dynamics: Sprint performance improves with age, but younger athletes recover faster from high-intensity exercise. Recognizing these differences is key to effective training and recovery strategies for young athletes.

CONCLUSION

AugFb research in motor learning highlights the significance of feedback type, KP and KR, and the timing, frequency, and modality of feedback, which influence motivation and performance (Tissera et al., 2022; Bugnon et al., 2023). Knowledge of performance enhances understanding of skill mechanics, while KR emphasises outcomes and promotes performance through a shift in attentional focus (Petancevski et al., 2022). The optimal timing and frequency of feedback depend on the complexity of the skill being learned, though feedback delivery, whether verbal, visual, or multimodal, should always be clear and concise (Keller et al., 2014; Jaszczur-Nowicki et al., 2021). Attentional focus plays a critical role in performance, with an external focus enhancing automatic movement control (Wulf and Lewthwaite, 2016). Positive feedback increases motivation and perceived competence, whereas negative feedback can detrimentally affect performance (Motro et al., 2021).

Recent studies have demonstrated the effectiveness of AugFb in improving performance in complex motor tasks (Nagata et al., 2020; Bella et al., 2023), challenging traditional views like the guidance hypothesis (Schmidt et al., 1989). Notable findings indicate that KR can yield immediate and long-term performance enhancements, particularly when delivered consistently at 100% (Keller et al., 2014), while the motivational boost associated with AugFb may be a key factor driving these performance improvements (Walchli et al., 2016). However, while KR is reported to impact sprint performance significantly, its effects on RSA remain unclear (Bella et al., 2023). Importantly, age-related differences play a significant role in RSA, as children and adolescents exhibit more rapid recovery from repeated sprints compared to adults, likely due to physiological factors such as their greater reliance on oxidative metabolism and faster rates of PCr resynthesis (Mujika et al., 2009)..

Finally, effective COD is crucial for athletes in team sports, necessitating specialised training that distinguishes it from linear sprinting (Buchheit et al., 2012). The differing influences of COD and linear sprint training underscore the importance of targeted training approaches to optimize athletic performance. Continued research is vital to refining training programmes that enhance athletic outcomes in competitive settings.

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