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Modifying Technique in Self-Paced Motor Tasks, by Joseph Vecchione, Catherine Madill, and Nicola J. Hodges

Technique change is foundational to the ongoing process of movement skill acquisition in domains such as sports, the military, or clinical environments. Consider the situation of an athlete who is experiencing discomfort from a rather unusual type of golf swing, or a swimmer who is consistently within the top 50 of her sport, but cannot seem to break into the top echelon because of inefficient mechanics of her turn and kick. These examples epitomize situations in sports where a change in technique is needed. Technique itself refers to the movement of body segments and their position and orientation, as they change during a motor task to enable effective performance (Lees, 2002). Although generally "better" technique will result in improved performance, the relationship between technique and performance is complex, dependent on many factors including the sport, the athlete, and the technique (Lees, 2002). Despite the prevalence of situations in sports where a change in technique is needed, there is a dire lack of empirical evidence concerning the relative effectiveness of technique change methods. Moreover, there is a lack of detailed understanding as to potential methods which can be used to change technique and importantly the characteristics and mechanisms which might be driving their effectiveness. Our aims in this chapter are to: 1) provide some definitional clarity regarding technique change; 2) detail various methods which have been studied in relation to technique change as well as evaluate associated empirical evidence; 3) determine common approaches and potential mechanisms across methods and; 4) make recommendations regarding research and application based on current knowledge.

Technique Change Definitions

There are three interrelated features which characterize technique change: it involves a permanent modification, this modification is to a previously acquired movement, and an existing or old technique is no longer desired and should be stopped, replaced or modified (see also Sperl & Cañal-Bruland, 2019). The process of technique change or modification is referred to in a number of ways and we have provided a summary of definitions in Table 1. We refer to these definitions as the 4Rs of technique change: Relearning and Resisting, Refinement and Regaining, reflecting various technique change scenarios that vary in their severity. At one end, technique change can be relatively drastic, necessitating not only relearning but also inhibition of a previous, undesired technique – what we term relearning and resisting. This drastic change, perhaps as a result of technology and/or sport science research, is expected to result in better performance outcomes. A commonly cited example is the "Fosbury Flop" high-jump technique, replacing the previous method of clearing the bar forwards not backwards. More subtle changes to technique have been described as technical refinement (Carson & Collins, 2011). Technical refinement does not require the cessation of an old behaviour, just a modification to an existing behaviour. A recent example of technical refinement can be found in track cycling, where the standard upright standing position for the start might be adapted to the more contemporary, forward standing start, with low forward torso and head position to reduce aerodynamic drag and increase speed (Merkes et al., 2019). A final way that technique change has been considered is as a process of regaining technique, which might be due to recovery from injury or a loss of form (Carson & Collins, 2011). In the regaining scenario, there is really no new learning but rather recovery of previous technique. Though cases of regaining may require the inhibition of undesired technique, it is not a consistent feature of this technique change scenario. The changes are typically small or subtle, which covary with improvements in fitness or injury. In general, technique change interventions are not always designed to improve performance, but rather may be instigated to prevent or recover from a technique that leads to (or could lead to) injury. They may be about change generally, not necessarily moving to an ideal or preferred way but promoting the need to do something different. This change may be required to improve performance, safety or health outcomes and as such can be highly individualized. Understanding the differences among these definitions helps to appreciate the broad scope of scenarios where technique change interventions can be applied and also hopefully inform as to when different approaches are needed.

Evaluation of Research

There is growing evidence that methods other than, or in addition to, direct instruction exist to change technique, even though the research in this area is still limited. One of the main challenges in this area is conducting controlled research that is dependent on the recruitment and ideally random allocation of athletes to various treatment interventions spanning multiple sessions, including retention tests and transfer to competition. To our knowledge, there are only four studies that have had a relatively large sample of athletes ($n > 30$), included measurement of comparison groups across multiple sessions, and importantly included retention tests to assess relatively permanent changes (Gray, 2018; Milanese et al., 2008; Milanese et al., 2016; Milanese et al., 2017). Moreover, there has been no assessment of efficacy of an intervention for transfer to competition and although retention tests have been used they have been limited to weeks (maximum 1 month; Gray, 2018). In contrast, there have been a small number of case studies that have documented lasting impacts beyond one month and also in competition (Carson et al., 2014; Collins et al., 1999; Hanin et al., 2002; Hanin et al., 2004; Williams et al., 2012).

In Table 2 we provide a summary of various methods that have been applied to technique change, along with information concerning common elements and research evidence. Many of the proposed methods are limited to case study evidence and, irrespective of whether the research is based on case studies or comparative studies, the time course of interventions is wide ranging. Relatively permanent changes are noted after as little as one session (e.g., the method of error amplification), whereas others appear to require weeks of practice (e.g., the Five-A method). There are other variations in factors that make comparisons across methods difficult, such as the athlete’s skill level, difficulty of the skill/technique, and inter-individual differences in the response to technique change interventions (Carson & Collins, 2015; Sperl & Cañal-Bruland, 2020). Good technique change research is obviously challenging, where there is a need to take a large group of experienced athletes, subject them to different interventions, and conduct longitudinal follow-ups and analyses to confirm relatively permanent change and effective transfer to competition.

In the following section, we introduce the various technique change methods, discuss key and potentially common elements with other methods, as well as speculate on mechanisms through which the methods will likely work to change technique. We also highlight research related to their effectiveness, speaking to the successful application of these methods for self-paced, closed motor tasks and sports.

Descriptions and research evidence for various technique change methods

1. Old-Way, New-Way

Description and procedures: The Old-Way, New-Way (OWNW) approach to technique change, also called Negative Practice (Lim et al., 2017), has been adapted from Lyndon's work in educational settings addressing habitual spelling errors in students (Lyndon & Malcolm, 1984). The aim of the intervention is to actively contrast an old-way with the learning of a new-way, which is thought to reduce inhibition (also called proactive interference) of the old on the new, promoting forgetting of the old. This comparative method has also been referred to as contrast training and it has been used in a variety of settings, including technique change in sport (Collins et al., 1999). Practicing the old-way, or what might be thought of as "the error", contrasts to more conventional direct instruction approaches, whereby errors are avoided (Adams, 1971).

The OWNW approach typically has three distinct phases; (1) preparatory phase, (2) mediation phase, and (3) application phase (Lyndon, 2000). In the preparatory phase, the goal is to clarify the difference(s) between the old- and new-way of performing a skill. This process of differentiation or error awareness requires elaboration between the coach and athlete and can be time intensive depending on the skill. This is really a process of perceptual training, where the learner is trying to form an understanding or image/template of what is desired and relate this to their current performance (Madill et al., 2019). There are five steps in the mediation phase, simplified as readiness, being able to describe the new-way, practising both old and new ways and identifying links between them, then practising both and describing differences, and finally continuing to alternate practice of the old-way and new-way for five attempts. This suggestion of five attempts is based on work with spelling errors (Lyndon, 2000), which are likely much simpler to identify and correct than errors involved in whole body movement, so the dosage is probably higher. In the application phase of the OWNW approach, the goal is to apply the refined skill in training. This application involves progressively decreasing the reliance on external feedback, while increasing environmental stressors and competitive demands to mimic performance conditions.

Research: With respect to sports, there have only been case studies attesting to the efficacy of OWNW with athletes (Hanin et al., 2002; Hanin et al., 2004; Lameiras et al., 2015). The most convincing data come from three case studies with high-level athletes across three sports (javelin, sprinting, swimming; Hanin et al., 2002; Hanin et al., 2004). In all three cases, a single trial, involving the three phases as described above, produced stable changes with >80 % frequency of desired technique. In a case study of an Olympic swimmer, stability was observed over an 8-month window, where the athlete improved their race times and starting speed in international competitions (Hanin et al., 2004). These case studies show that the OWNW method is potentially an efficient intervention tool for relearning and resisting scenarios related to technique change.

2. Identification-Correction-Control (ICC) Program

Description and procedures: The Identification-Correction-Control (ICC) program is a three-step technique change method developed and tested by a group of researchers in Finland, working with internationally competitive elite athletes (Hanin & Hanina, 2009). The three steps of the ICC program include 1) identification of an individually optimal movement pattern, 2) control and monitoring of this movement pattern, and 3) correction of habitual performance errors. The ICC program is an interdisciplinary approach that has roots in skill acquisition and psychology principles, built upon ideas outlined in OWNW (and contrast training). The main difference between OWNW and ICC programs is the added dimension of emotion control through sport psychology principles. This is evidenced by their two-classification systems used to identify the target of emphasis in a technique change intervention – "emotion-focused" or "action-focused" coping (Hanin & Hanina, 2009, p. 49).

The ICC program places an emphasis towards what the authors term "action-focused" coping strategies by focusing on the movement execution and how it relates to perceptions and the emotional state of the performer (Hanin & Hanina, 2009). "Emotion-focused" coping is emphasized more when an athlete shows challenges with emotional control, perhaps in high-pressure situations. In both scenarios, emotion and effort regulation tools (i.e., self-rating tools and imagery) are used to get athletes into what are referred to as "individual zones of optimal functioning" (Robazza, 2006), before engaging in contrast-focused practice. Typically, the first step of the ICC program is completed in concert with the athlete by reviewing past performances and establishing what is individually optimal in regards to their movement, emotion, and effort to improve performance during practice and competition. The second step involves error awareness and perceptual training of the desired movement pattern, which leads into the third and final step of contrast training involving alternation of the old and new way. These three steps are typically carried out in a single session (ranging from ~1-3 hours) with specific direction to the athlete as to how to apply what they have learned into their practice, thus reinforcing the correct technique. There is a clear overlap not only in the intervention process of the ICC program and OWNW method, but also in the empirical evidence. However, we list the ICC program as a separate method due to its extensive application across a variety of sports and how it has developed as a unique model of application from the OWNW method (with detail given to the movement analysis and psychological analysis).

Research: The ICC program has been studied with a large array of athletes across different sports, including track and field events: high jump, long jump, pole-vault, javelin, hammer, shot-put, 100m and 400m sprints; individual sports: swimming, diving, racing, pistol shooting, sailing, bowling, and free-style skiing; and team sports: volleyball and soccer (Hanin & Hanina, 2009). However, the research has been limited to case studies and only a small number of these have been published (in swimming, javelin, sprinting, and diving, Hanin et al., 2002; Hanin et al., 2004; Hanin & Hanina, 2009). Besides the diving case study, the other research was referenced above in relation to the OWNW. In a response to multiple commentaries regarding their article outlining the ICC program, a case-study was discussed of an Olympic diver who was practising to regain his previous performance in international competition (Hanin & Hanina, 2009). The authors explained how they worked with the diver to develop an optimal yet individualized technique through review of past performances, how they established optimal levels of emotion and effort to improve performance during practice and competition, and how they supplied direction on how to apply the ICC criteria into a consistent training regimen. This arguably resulted in a successful return to previous form and the winning of multiple competitions in the upcoming season (Hanin & Hanina, 2009).

One of the strengths of the work with this ICC method is the matching of the technique change intervention with subsequent improvements in performance, often in international competitions (Hanin et al., 2002; Hanin et al., 2004; Hanin & Hanina, 2009). With respect to comparative studies, the step of identifying individually optimized movement patterns makes it difficult to compare across groups of individuals undergoing different methods, even though there will likely be technique similarities across individuals. The ICC program appears to have a strong record of success, adding to other evidence attesting to benefits of the OWNW to technique change. Although both the OWNW and ICC programs are grounded in mechanisms of contrast between desired and undesired actions (and as such, reduction of proactive interference), the appreciation of the psychological state and willingness of the athlete to undergo such a change is considered integral to the success of the ICC program.

3. Method of Amplification of Error (MAE)

Description and procedures*:* In the Method of Amplification of Error (MAE), the performer is typically instructed and given feedback to purposely exaggerate the technical error (Milanese et al., 2008). In rehabilitation literature, this error has been exaggerated through the use of robotic devices and the learning has been a result of adaptation to the error after the device is removed (e.g., Patton et al., 2013; Reisman et al., 2007). However, we are unaware of studies where physical devices have been used to exaggerate undesired techniques in sport settings. In the method used by Milanese and colleagues (2008), performers alternated between attempts to perform the movement with repetitions that exaggerated their identified technical error (through the use of cues) and attempts without an error. This error/no-error type of training has similarities to contrast training typified in the OWNW. However, for the MAE, in the non-constrained /no-error trial, no instruction is provided about what a correct or desired movement should be. As such, learning is believed to be a consequence of correcting and adapting for large mistakes, rather than trying to match a desired technique goal (Milanese et al., 2008). The assumption with MAE is that performers will adapt their technique through the augmented intrinsic feedback about how the movement feels and looks and in response to the impact of the movement error on performance outcomes (Milanese et al., 2017). In terms of the time course of such interventions, there are typically pre-instruction trials (i.e., a baseline assessment where the authors identify the main technical error), intervention trials (typically one practice session consisting of 3-4 rounds of alternating between error amplification and non-constrained trials), and post-intervention trials including delayed retention tests (Milanese et al., 2008; Milanese et al., 2016; Milanese et al., 2017).

***Research*:** Unlike many of the technique change methods, the effectiveness of MAE has been empirically demonstrated when compared to randomized control groups, as well as to traditional methods of direct instruction. However, this method has only been investigated in sports by one group of researchers (Milanese et al., 2008; Milanese et al., 2016; Milanese et al., 2017). In a comparison of the MAE to a direct instruction and no-intervention control group, in a study designed to change technique in the standing long jump, adolescents showed significant improvements in jump distance in both the MAE and direct-instruction groups post-session (Milanese et al., 2008). However, in a 1-week delayed retention test, the MAE group outperformed both groups. In more recent work involving kinematic analyses as well as qualitative measures of technique from expert coaches, there were some indications that the MAE was a beneficial technique change method. In one study involving experienced golfers and one practice session, no statistical differences in kinematic parameters of club head speed and ball speed, linked to golfing performance, were noted between a MAE group and a direct-instruction and no-instruction control group (Milanese et al., 2016). However, the MAE group increased club head and ball speed to a greater degree and showed a greater reduction in technical errors as compared to the other two groups. Similar results emerged in a second study with experienced weightlifters (Milanese et al., 2017). Again, there was a greater reduction in number of technical errors in the MAE group compared to the direct-instruction and no-instruction groups. Although both the MAE and direct instruction groups improved across practice trials in key kinematic variables related to horizontal displacement of the barbell, which was a selected error identified by the coach, there were no statistical differences between the three groups at the end of one practice session or after a 1-week delayed test.

In summary, although the data are suggestive of the success of this method following only one practice session, the performance data are not strong, especially when more objective measures of performance are considered. The authors cite the possibility that more training sessions are likely required to reveal statistical differences in these performance measures across the groups. Moreover, although the MAE shows some evidence that it is superior to the traditional approach of direct instruction regarding the desired technique, the long-term retention across weeks or months and in competition settings has not been tested. In all three studies by the Milanese group, an error amplification group has only been compared to a direct instruction group or a no-feedback control group. To be able to make recommendations for use of this technique in the field, comparisons to other technique change methods, like the OWNW, are needed.

4. The Constraints-Led Approach (CLA)

***Description and procedures**:* The Constraints-Led Approach (CLA) to motor behaviour and development, first proposed by Higgins (1977) and later applied to development by Newell (1986), is based on the consideration of behaviour as a consequence (or movement solution) of various task, environment, and person constraints. These constraints contribute to every athletic endeavour, whereby things like body size, prior experience, and habits interact with equipment changes (such as ball or racquet size) or rules (such as not allowing more than 3 steps before take-off in a jump), to bring about behaviours. If we consider the example of a golfer practicing a drive, by improving the golfer's strength we are influencing individual constraints to bring about a change in behaviour, whereas varying the type of golf club used is a manipulation of task constraints. Practice driving into a net or on the links is an environmental constraint which will also impact movement behaviour.

Although task constraints can be broad ranging, most often it is physical task constraints which are manipulated to bring about technique change (Renshaw et al., 2020). According to the CLA (or what is also referred to as ecological dynamics), coaches manipulate equipment constraints to aid in the emergence of individually-optimal techniques (Davids et al., 2013). Through manipulation of a constraint (e.g., modification of the task, such as sprinting with resistance via a sled/resistance band), a change in behaviour can be brought about – not necessarily with the awareness of the desired behaviour by the athlete (e.g., athlete will adopt forward leaning posture to accelerate). As such, there is no explicit instruction about errors, desired technique, or error correction methods. This absence contrasts to other technique change methods where conscious awareness and adjustment of an identified technical error, often towards an individually optimal technique, are critical components of the intervention. Of course, a degree of creativeness and perhaps trial and error are needed to find the right constraint(s) to bring about a behaviour, which may also necessitate some awareness of the error and desired technique on behalf of both the coach and athlete.

Research: To our knowledge, there is only one experimental study where the constraints approach has been evaluated in a technique change intervention (Gray, 2018). In this study, three groups of baseball players received six sessions of extra-scheduled batting practice in a virtual baseball simulator. The aim of the training was to change hitting outcomes (and indirectly technique), by increasing launch angle and exit velocity of the ball (parameters correlated with increased home runs). The constraints group practised with a physical barrier in the virtual environment, which had adjusted height and distance across trials based on hitting performance, to modify task challenge. The two other groups received either body-focused or bat-focused instructions about coach-informed good technique. However, they received no other feedback beyond where the ball travelled on the simulated field and there was no adjustment in task challenge. In post-tests, the constraints group showed a significant improvement compared to both instruction groups in terms of key kinematic parameters related to their baseball swing technique (increased launch angle and increased exit velocity). Although this research is encouraging for the use of constraints in technique change, further research and better comparison groups are warranted (where all potential motivational, feedback, and information sources are controlled). It would be of interest and importance to compare the CLA to other technique change methods, such as the OWNW or error-amplification method.

5. The Five-A Model of Technical Change

Description and procedures: The Five-A Model (Carson & Collins, 2011) is an interdisciplinary guide for technique change which pulls together multiple theories from motor learning and psychology. The five stages (Analysis, Awareness, Adjustment, (Re)Automation, Assurance) provide coaches and practitioners with both tools and a roadmap for applying a technical change intervention for experienced athletes. The Five-A model was proposed to aid in making subtle changes to technique in order to refine or regain previous form (Carson & Collins, 2011). This model has received conceptual and empirical validation through multiple case studies (e.g., Carson et al., 2014; Carson et al., 2016; Collins et al., 1999).

One of the defining features of this five-stage approach, applied in each of the studies referenced below, is the use of contrast drills, similar to those discussed in the OWNW. In addition to contrast drills, the multi-step approach relies on biomechanical analysis, psychological support, and application of motor learning principles (e.g., verbal/visual feedback, focus of attention, part practice) to successfully change technique. Although it is not empirically understood what aspects of the technique are responsible for success or what is the relative importance of the various steps, the authors would likely argue that all steps are necessary.

Research: Early work involving the regaining of previous technique and performance after injury in an Olympic javelin thrower, laid the foundation for what would later evolve into the Five-A model (Collins et al., 1999). In a case study aimed at regaining previous pre-injury performance while refining technique in an Olympic weightlifter, improvements in both technique and performance of the snatch were established after the Five-A model was applied across a 10-week period (Carson et al., 2014). The interdisciplinary intervention included a three-dimensional video kinematic analysis of the error as a template for reference and feedback, in comparison to the “correct” technique, ongoing reporting of self-efficacy through questionnaires, mental imagery practice, and integration of coaching and therapy staff to prescribe exercise progressions. The change in technique was maintained at a 2-year follow-up, the athlete avoided further injury, and they achieved a personal best at the European Championships. While both of these examples highlight the long-term efficacy of the Five-A, the time course and effectiveness of the interventions can range.

In a set of case studies involving three elite golfers’ refinement of swing mechanics, the intervention’s effectiveness and duration ranged for each golfer (Carson & Collins, 2015). Two of the three golfers successfully maintained their new technique (one golfer through ~10 weeks of training with no follow-up; the other at ~28 and 36-weeks follow-up). The third golfer reverted back to their previous technique at both ~25 and ~33-weeks follow-up, which the authors attributed to the athlete’s lack of “buy-in” to the method. The authors did not relate these technique changes to the athletes’ golf performance or even to injury avoidance. These case studies reflect the real-world challenges in applying technique change methods with the range in their time course and effectiveness. The interdisciplinary approach in these examples, utilizing psychological, biomechanical, and motor learning principles, highlight many factors that could play a role in effectively changing technique. To date, there is no experimental research where individuals have been allocated to different intervention/control groups and compared across multiple sessions.

6. Traditional Method, Direct Instruction

Description and procedures*:* Instructing the desired technique, which could be achieved through various modalities, is the hallmark of what others have termed more traditional or conventional technique change methods (e.g., Hanin et al., 2004; Milanese et al., 2017). It is difficult to ascribe this direct instruction approach to one researcher or set of researchers, as it is more of a default method of instruction. Individuals are told or shown what they should be doing and then are either left to figure out how to achieve a desired goal or are prescribed steps to achieve a desired state. Instruction is a broad umbrella term that can include video, live demonstrations, verbal feedback, instructional cues that focus attention to supposed key aspects, and verbal explanations about what is required and sometimes about what is deemed in error (Hodges & Franks, 2002). With respect to instruction, there are various variables that will affect both performance and learning outcomes. Verbal instruction, demonstrations, and cues can have different effects on how the performer learns (Hodges & Franks, 2002; Lohse & Hodges, 2015). In the case of cueing, whether an athlete's attention is directed to their body (termed an internal focus) or the movement outcome (termed an external focus), is a known factor influencing the efficacy of instruction in terms of short-term performance and longer-term learning (Wulf, 2007, 2013). Attentional focus has also been shown to be an important consideration in a technique change intervention (Wulf & Su, 2007). Although attentional focus is often directed to the movement and body in the majority of technique change methods (perhaps with the exception of CLA), as the performer approaches the later stages of the intervention there seems to be a shift to externally-focused cues on the environment and performance outcomes, in the hopes of stabilizing technique and performance in competition (e.g. Five-A, ICC). Despite known effects of direction of attention on performance, it is unlikely that direction is the main ingredient underlying the success of an intervention.

Research: Of the literature we have reviewed on technique change, there are four studies that have included a direct instruction comparison group (Milanese et al., 2008; Milanese et al., 2016; Milanese et al., 2017; Gray 2018). As mentioned in a previous section, in two of these studies (Milanese et al., 2016; Milanese et al., 2017), there were no statistical differences in key kinematic variables between direct instruction and MAE, though coaches reported MAE to have led to a greater reduction in technical errors compared to the direct instruction method in training and at retention. However, direct instruction led to reduced technical errors in weightlifting technique during retention, as compared to the no-intervention control group (Milanese et al., 2017), but this was not the case (i.e., differences between direct instruction and control groups) during training or retention of the swing technique in golf (Milanese et al., 2016). In two other comparative studies, the direct instruction groups performed worse than the comparison groups after one session and six sessions, respectively (MAE, Milanese et al., 2008; Constraints, Gray, 2018). Though the comparison groups in the constraints experiment differed in their focus of attention (internal, external), and performance outcomes (external focus outperformed the internal focus group), they would both be considered direct instruction methods (Gray, 2018). Indeed, in this baseball study by Gray (2018), providing externally-focused instructions on the bat and the ball led to improved performance outcomes (e.g., increased mean exit velocity of the ball) compared to internally-focused instructions onto body kinematics on the 24-hour post-test (although the CLA group outperformed both). Both direct instruction groups improved their mean launch angle (indexing technique), and even though the external-focus group performed better at the post-test than the internal-focus group, these groups did not differ at the 1-month follow-up, but the CLA group maintained its technique advantage.

Based on the available evidence, we should not dismiss the effectiveness of direct instruction for changing technique. By itself, it may not be sufficient to bring about lasting change or the same degree of change as other methods, yet research is still lacking regarding the necessity to include error contrasting, amplification, or indirect methods of technique change which bypass the need to focus on technique at all (e.g., constraints) in order to efficiently and effectively bring about lasting change. Of course, there are good and poor ways of delivering instruction (with respect to frequency and content), and merely dismissing the relative effectiveness of a method based on a few studies where only specific cues were provided, rather than specific and progressive steps, is likely premature.

Other technique change methods

Outside of the established technique change methods that have been reviewed in this chapter, there may be potential alternatives that offer solutions to technique change scenarios but have not necessarily been considered as “technique change methods”. One potential alternative that has yet to be empirically tested is part-practice, whereby tasks with multiple components are practised independently (e.g., components of a gymnastics’ routine). Serial tasks that have multiple components may benefit from part-practice (Fontana et al., 2009). Some technique change methods use part-practice principles to help contrast the correct and incorrect technique

(Collins et al., 1999; Lameiras et al., 2015). In the ICC program, progressive part-practice is explicitly described as part of their program. They describe the second stage of control and monitoring, as the “deliberate and step-wise practice of the entire chain of optimal movement patterns from the first component to the last component in the chain” (Hanin & Hanina, 2009, p. 53). Another method that might be deserving of study is implicit learning, where the method of practice is based on limiting the explicit buildup of knowledge about how to perform. This method is thought to keep the individual at a level of performance that is relatively automatic, with low attention demands, in comparison to explicit instruction methods that encourage the decomposition of a skill into verbalizable components (for a recent review see Masters et al., 2020). Some of the ways in which implicit learning has been enacted include using dual-tasks to direct attention away from what a person is trying to learn; errorless learning, where individuals progress from easy-to-difficult practice conditions in an attempt to limit the buildup of knowledge; and analogy learning where complex skills and interactions are conveyed by simple analogies to well-known examples.

Summary of methods and identification of common and different elements

As should be apparent from our review and the summary provided in Table 2, the similarities between methods are almost as notable as their differences. That is, many of the methods are based on developing awareness of the undesired technique (or error) in order for change to occur, perhaps with the exception of the CLA and potentially direct instruction about what to do (rather than what not to do). This awareness is a critical component of the OWNW approach as well as any method based on contrasting. In addition, many of the methods have what we term a direct instructional approach, where the desired technique or goal is prescribed and/or demonstrated and feedback is given that is typically technique and body-focused (e.g., Direct Instruction, OWNW, Five-A Model, ICC Program). Again, the constraints approach is one exception here, in addition to the MAE where the explicit goal is to exaggerate what is wrong, rather than try and mimic what is considered “correct”. These distinctions between error awareness and striving toward a prescribed ideal may prove to be important elements of successful technique change interventions, but as yet, change can be manifested in the absence of either (although good empirical research is lacking).

Rather than considering error awareness and technique focused instruction as separate components, what is common among many of the technique change methods is the combining of these components through contrasting practice (e.g., OWNW, Five-A Approach, and ICC). Although again good empirical research is lacking, at least in the sports domain, there appears to be some benefit associated with the continual comparison between the old and the new which leads to successful changes in technique. The reason many coaches and practitioners find it difficult to change habitual errors in technique is because they have to create in their athletes an alternate (new) response to a stimulus which is not as robust as the original (old). As such, an old technique can resurface in competition and under stress. It is thought that contrasting the new way to the old way, in the presence of some augmenting instruction or perhaps a physical device, will bring about awareness of the error and help to inhibit potential interference (Lyndon & Malcolm, 1984).

Contrasting has been suggested to work through a mechanism known as proactive inhibition. Proactive inhibition diminishes the competition between motor responses in a given context, increasing the retrieval of the desired response (Lyndon & Malcolm, 1984). Understanding that an undesired technique may reappear (i.e. a lapse or relapse of behaviour) provides some rationale for practicing the error. Appreciation for these competing mechanisms seems to be critical, given that we cannot simply undo previous learning (Bouton, 2000). It is possible that an old technique may resurface under pressure or in competition, highlighting the importance of specificity of the environment and context in relearning a new technique, facilitating the selection of the desired response under conditions when it is needed.

By bypassing the focus on either the old or newly desired technique, the constraints-led approach seeks to bring about change merely as a result or consequence of a new goal or constraint. Because there is no explicit desired goal, but rather a number of potential solutions to solve a performance goal the idea is that the performer adapts their performance to the current task constraints through a process of self-organization (Davids et al., 2013). Although there has been some success with this method, even when the physical constraint is later removed to assess transfer, it is unclear whether this method will be effective at developing techniques which are stable over time and durable in the face of competitive stressors. If the discovered technique or solution is not required to hit a ball forcefully or score a point in competition, yet a change in technique is still deemed important to compensate for changes to rules or to help avoid injury, what would be the motivation to continue to display a particular technique? Similar issues arise when considering error amplification, where errors are magnified in practice and the desired action is thought to develop as a result of self-organization (rather than direct attainment of a desired action). In the MAE, as different to the constraints approach, however, there is clearly some awareness of what should not happen. Therefore, learning would more likely lead to the replacement of an old, undesired way of performing, aided by the contrasting which takes place where the performer alternates between exaggerating their error on one trial and not making an error on a subsequent attempt.

In summary, it appears that in general there are more similarities than there are differences between the technique change methods which have been applied in sports to date. Common elements such as error awareness, practicing the error, and contrasting with another more preferred action seem to feature highly in these methods, potentially playing a key role in provoking "permanent" change in technique. However, because technique change can also be brought about indirectly, through manipulation of constraints, these facets detailed above (i.e., error awareness, practicing the error, and contrasting) do not appear to be necessary conditions for success, at least in the short-term. In the discussion that follows we consider how these various approaches and associated elements might be best applied under the 4Rs of Relearning and Resisting, Refining and Regaining.

Applying technique change methods across the Four Rs

Since different scenarios exist that necessitate a technique change intervention (e.g., avoiding potential injury, improving performance), there may be specific technique change methods that are more or less suitable to these applications. Currently, there are no guidelines as to how to select an appropriate technique change method based on context. However, it appears that certain technique change methods may be more applicable in particular scenarios than others (see Table 2 for scenario details for each method). One of the first steps in applying these methods, regardless of the scenario, is to consider the individual (or group) and the technical error/skill in question. Understanding of the competition demands, the athlete's proficiency, and previous coaching, as well as the current psychological state of the performer and their motivation, are important pre-intervention considerations. Additionally, it is important to understand how the technical error is affecting performance. Classifying the main error correctly can have implications on both the intervention design and ultimately, the success of the intervention (Corte et al., 2015). Even with a detailed diagnosis of the technical error, individuals will respond differently to the intervention based on previous coaching and their psychological mental state (Carson & Collins, 2015). This multi-dimensional approach prior to intervention, based on individual technical and psychological needs, is consistent with recommendations from various technique change methods, including the Five-A Model and the ICC program.

1. Relearning and Resisting

When a drastic change in technique and a suppression of previous form are required, the evidence to date supports employing the Old-Way New-Way method (Hanin et al., 2002; Hanin et al., 2004; Lameiras et al. 2015). One of the challenges with resisting an old movement is that the same stimulus (perceptual input) remains, and thus the "programmed" response to the stimulus may persist. Contrasting the correct and incorrect technique seems to be a critical feature that applies to the scenario of relearning and resisting. This direct instructional approach may be necessary to change technique and resist habit-based errors through common elements such as alerting to the error, practicing the error, and contrasting the error with the newly desired action (see also the ICC program and Five-A Model). Though the Five-A model has been framed as a tool for subtle changes to technique (i.e. refinement) and regaining previous form, there is reason to think it can successfully be applied to relearning and resisting, as long as the OWNW is used in the awareness and adjustment stages.

2. Refinement

Technique refinement, which is a subtle change to a finely tuned skill, is linked to the ongoing process of skill expertise in high-level performers. It is likely to be the most commonly presented technique change scenario for coaches and practitioners (Carson & Collins, 2011). The individual's skill plays an important role in deciding on the best technique change approach. For athletes who have highly tuned movement patterns to certain conditions as a result of years of performing, a relatively direct instructional approach to technique change may be most effective. From the literature reviewed, the case studies that were successful with high-level athletes (e.g., medalists at the international level) often cited the need to elicit conscious awareness of both the technical error and desired technique (Carson et al., 2014; Collins et al., 1999; Hanin & Hanina, 2009; Hanin et al., 2002; Hanin et al., 2004). Alternatively, if athletes are younger and/or less experienced, such that the techniques are more malleable and less ingrained, the need to directly instruct and contrast will be lessened and constraints-based methods could be considered.

In technique change scenarios where a subtle change to technique is required, there is positive evidence supporting each technique change method reviewed. However, there are three technique change methods that have been exclusively applied to refine technique: direct instruction, the constraints-led approach, and error amplification. Because refinement is the most commonly studied of all the technique change scenarios there are more examples of successful interventions.

3. Regaining

Performers who are regaining their technique – perhaps after injury, pregnancy, or other life circumstances, are looking to re-establish previous technique and performance outcomes. This regaining may also be needed for athletes who see a consistent decrease in typical performance or experience the inability to perform a previously automatic skill, termed “loss move syndrome” (Day et al., 2006). Regaining is a challenge to any clinician rehabilitating an injured athlete who needs to mitigate the risk of re-injury. For example, there may be known biomechanical risk factors associated with the degree of knee flexion during landing mechanics, associated with injury to the anterior cruciate ligament.).

It appears that with regaining, psychological assessments and supports, in addition to analyses of previous performances, are important. In the literature we reviewed with respect to regaining (e.g., Carson et al., 2014; Collins et al., 1999), athletes engaged in mental imagery practice throughout the intervention, as part of the Five-A model. The imagery was designed to change their experiential memory of the past, build confidence, and reduce the need for physical practice which could aggravate any past injuries. Though evidence for the efficacy of the Five-A Model is based solely on elite athletes competing in international competition, there is no reason to suspect that the same success would not be seen with lesser skilled or younger athletes looking to regain their technique.

In the case of regaining, the goal is to achieve previous performance levels, though the starting points may differ in that a performer may be returning from injury, or is otherwise healthy. There does not appear to be any notable differences in approach based on these factors. With regaining technique, there is likely conscious awareness of the problem (i.e., the need to regain previous performance), which lends itself to more direct instructional approaches. Constraints-based methods and error amplification have not been studied in this scenario, so their potential efficacy is undetermined. Because it is less about what not to do, and more about aiming for a past technique, error amplification would be challenging. The constraints-based method may prove to be useful in this regaining scenario as it puts the emphasis on attaining an outcome (i.e., previous performance), rather than a specific movement form. Regaining of form may be difficult given changes to the individual as a result of injury, age, or other factors.

In summary, relearning and resisting and regaining have received the most empirical study and positive support. This has come from researchers working with direct instructional approaches involving awareness of error and of the desired movement, as well as contrasting.

For refinement, both direct and indirect instructional approaches have been successfully applied. As such, until more research becomes available, current technique change guidelines should be scenario specific.

Conclusions and future research

The literature on technique change specific to sport, is largely dominated by case studies. The collective of rich and detailed accounts from various technique change scenarios helps to define commonalities in process, specific elements, and potential mechanisms that underlie stable changes to well-established skills. However, there are very few examples of interventions where technique change methods have been compared across experimental and control groups, either in sport or in other movement applications. Usually the control comparison, where there is one, is a so-called "traditional", direct instruction approach. However, it should be clear from this review that we need to make comparisons across other methods, with a focus on isolating mechanisms that are driving a successful change (such as contrasting or error awareness). More of these non-traditional technique change methods should be studied and compared in both experimental and field based setting, in order for practitioners to make claims about relative effectiveness (and efficiency).

Currently, little is known about the awareness and frequency of application of these technique change methods among sport coaches and practitioners (e.g., therapists, strength & conditioning coaches). Although it has been suggested that coaches do have a process by which they approach technique change, there are inconsistencies in the steps taken and no evidence of scientifically informed best practices to intervene (Carson et al., 2013; Kearney et al., 2018). There are both knowledge and application gaps related to technique change interventions in sport.

Future research should be directed at isolating common elements and mechanisms of technique change through controlled experimental research designs. Once we better understand the critical ingredients of an intervention then more robust guidelines can be formulated, and it will be possible to direct research efforts to determining limiting factors or participant interactions impacting success. It is also important to continue to gain insights into current practice and knowledge among sport practitioners (e.g., therapists, strength & conditioning coaches) from a variety of sports, to help in evaluating the type and use of various technique change methods to inform knowledge transfer activities and research into these methods. As we gain greater insight into the most effective strategies to effect lasting physical movement change in specific scenarios, we can move towards more efficient and effective training across all sport and rehabilitation domains.

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Table 1

The Four Rs of Technique Change Scenarios

Terms/Sub-terms	**Definition**	**Reference**
Technique change	The permanent modification of an already acquired skill where the task goal remains the same	(Sperl & Cañal-Bruland, 2019)
i. **R**elearning & **R**esisting	Drastic change to technique which will necessitate not only relearning of the skill but also the inhibition of a previous, undesired technique	
ii. **R**efinement	"An evolution of technique" that includes subtle changes to finely tuned skills	(Carson & Collins, 2011, p. 147)
iii. **R**egaining	"Returning to a previous state of optimal technique from current suboptimal execution"	(Carson & Collins, 2011, p. 147)

Table 2

Various Technique Change Methods and Studies Associated With Each Technique, Along With a Description of Common Elements and Types of Sports and Scenarios Where These Methods Have Been Studied.

Method	Definition	Common Elements	Sport Skills	References	Application (Four Rs)
Old-Way, New-Way/ Identification-Control-Correction Program	Repetitive contrasting of movement error with desired technique / A systematic approach to identifying an individual's optimal technique	Direct instruction Practising errors & correct technique Error Awareness Contrasting Technique-focused feedback (internal FOA on difference)	Swimming block-start, Javelin, Sprinting, Tennis Serve, Diving	(Hanin et al., 2002, 2004; Lameiras et al., 2015; Hanin & Hanina, 2009)	Relearning & Resisting, Refinement, Regaining
Error amplification/ Augmentation error	Exaggerating the movement and contrasting it with attempts to achieve the	Indirect instruction (mostly) Practising errors Error awareness	Broad Jump, Golf, Weightlifting	(Milanese et al., 2008, 2016, 2017)	Refinement

	desired technique	Contrasting Technique-focused feedback (on error) (internal FOA on error)			
Constraints Led Approach	Manipulating individual, task & environment constraints to change technique	Indirect instruction Practice to achieve outcome Low error awareness Outcome-focused feedback (external FOA)	Hitting in Baseball	(Gray, 2018)	Refinement
Five-A Model	A five-step approach requiring Analysis, Awareness, Adjustment, (Re)Automation, Assurance	Direct instruction Practising errors & correct technique Contrasting Error Awareness Technique focused feedback (internal FOA on difference)	Golf, Olympic Weightlifting, Javelin	(Carson et al., 2014, 2016; Collins et al., 1999; Carson & Collins, 2011)	Refinement, Regaining

Traditional (direct Instruction only)	Providing a verbal and/or visual description about the desired technique and feedback related to the error	Direct instruction Practising correct technique Error Awareness Contrasting Technique focused feedback (internal FOA on difference)	Hitting in Baseball, Olympic Weightlifting, Golf swing, Broad-jump	(Milanese et al., 2008, 2016, 2017; Gray, 2018)	Refinement

*FOA = Focus of Attention