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The Revolution of Skill Acquisition in Sports: Comparing Linear and Non-Linear Pedagogical Methods to Teach Adolescents the Wide Receiver Stance and Start in American Football

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Abstract

In the last decade, the philosophy behind deliberate practice and traditional learning methods have received criticism for the limitations as a learning method. The purpose of this study was to compare the effects of linear and non-linear pedagogical methods for teaching the wide receiver stance and start to adolescents. Pre- and post-test of five-, 10- and 20-meter sprints from a wide receiver stance were conducted. Participants were randomly assigned to either a traditional learning (TL) group, or a differential learning (DL) group based on their age and previous experience playing wide receiver. The groups received two different interventions, one based on traditional corrective and instructive teaching, and the other based on the principles of differential learning. Three separate Repeated Measures ANOVA were used to analyze the data. Only the DL-group were shown to improve from pre- to post-test (for the five- and 20-meter distances). The TL-group showed no improvements from pre- to post-test. The results show the potential of DL as an alternative to traditional learning that has the potential to be a more effective method for teaching transferable motor skills. While Rate of Attendance was a significant covariate for 10-meters, the relationship to performance was inverted, and together with mostly null findings between Rate of Attendance and improvements seem to support the non-linearity of systems. It is suggested that non-linear pedagogy is a more suitable method than TL for different individuals regardless of their previous experiences or internal dynamics. Practical implications and recommendations for future research are discussed.

Keywords: non-linear pedagogy, ecological dynamics, differential learning, deliberate practice, traditional learning, American football, Adolescents

The Revolution of Skill Acquisition in Sports: Comparing Linear and Non-Linear Pedagogical Methods to Teach Adolescents the Wide Receiver Stance and Start in American Football

When it comes to motor and skill acquisition in sports, the most common and dominant model is the theory of deliberate practice (Chow et al., 2015). This theory states that young athletes should practice intensely and focused, no matter the task, and have an expert supervise their practice and give them instruction-based feedback on their performance when they do not perform as instructed (Cote & Erickson, 2015). This theory has shaped the idea of early specialization in sports where it is hypothesized that through specializing, and training intensely in one sport from a very early age while being supervised by an expert coach, one is likely to progress at a fast rate and achieve a mastery level of performance (Güllich et al., 2022). It is very common to hear the reference to the famous 10,000 hour rule proposed by the famous author Malcolm Gladwell (2008) in his book *Outliers*. It is a simple and easy to understand rule that says that to achieve expertise in a given field, an individual has to put in 10,000 hours of practice to achieve mastery. This is a very attractive rule to cite and to live by because of the simplicity that it brings, and that all one must do to become the next Michael Jordan or Tom Brady is to put in the thousands of hours of practice. However, today it is known that not everyone that puts in 10,000 hours of work becomes the next Michael Jordan. Research has shown that only about 18 % of the variance in hours of accumulated practice explains the differences in performance level in sports (Macnamara et al., 2014). Furthermore, when it comes to elite level performers in sports, accumulated practice hours only account for one % of the variance in performance level (Macnamara et al., 2016).

Criticism of deliberate practice

In the famous study by Ericsson et al. (1993) which is often cited as the study that introduced the idea of deliberate practice, they examined the number of hours performers had spent to reach a mastery level of performance. In the same study they claimed that differences in performance level is related to difference in amount of accumulated deliberate practice, and that talent comes from intense training with guidance from an expert for a minimum of 10 years. This traditional pedagogical model for skill acquisition has received a lot of criticism over the years (Chow et al., 2015). The method used by Ericsson et al. to collect data for the accumulated number of hours of deliberate practice has been shown to be flawed since it relied on self-estimation of retrospective information (Macnamara et al., 2014; Macnamara et al., 2016; Tucker & Collins, 2012). The study by Simon and Chase (1973) heavily influenced the theoretical approach by Ericsson et al., and in that study Simon and Chase showed that elite-level chess players had achieved an elite-level of performance by completing between 3,016 hours and 23,608 hours. Furthermore, this large difference in number of accumulated hours of deliberate practice by elite-level performers was also highlighted by Gobet and Campitelli (2007) where they reported an interval between 728 and 16,120 hours for chess players to reach the level of master. Moreover, in the meta-analysis by Macnamara et al. (2014), they concluded that deliberate practice is relevant and useful, but not to the extent that has been argued by Ericsson and Moxley (2012) and Ericsson et al. (1993).

Deliberate practice is not enough

Tucker and Collins (2012) proposed that deliberate practice, and other environmental factors are not enough to produce elite-level performers in sports. They further suggested that it is the combination of genetics and training factors that lead to elite-level performance. Moreover, Meinz and Hambrick (2010) has proposed that that the working memory capacity is one highly stable genetic trait that is heritable and is predictive of expert performance. Furthermore, in the two studies by Hambrick et al. (2014a) and Hambrick et al. (2014b), they suggest that the combination of practice design and the genetic makeup of each individual athlete is more important than the amount of time spent practicing. In fact, Ullén et al. (2016) proposed that there is a gene-environment interaction when it comes to the development of expertise. This is because there are several psychological traits which are heritable and correlate significantly with deliberate practice. It is therefore suggested that there is an element of heritability when it comes to differences in accumulated deliberate practice, and it is suggested that we should consider the interaction between genetics and environment to explain differences in deliberate practice and in turn differences in performance level. Moreover, it is suggested that compared to the traditional approach of early specialization, multi-sport engagement during an athlete's youth career is linked with better performance, lower risk of injury and burnout in the long run for an athlete's career (Barth et al., 2022; Giusti et al., 2020; Güllich et al., 2022; McLellan et al., 2022).

Response to the criticism of deliberate practice

In response to the previously mentioned criticism, Ericsson and Harwell (2019) re-analyzed the studies used to calculate the overall explained variance in the study by Macnamara et al. (2014) and found that several of the 88 studies used in the meta-analysis did not include practice that could be characterized as deliberate practice as defined by Ericsson et al. (1993). Ericsson and Harwell found that after removing the studies that did not fulfill the criteria of deliberate practice from the meta-analysis by Macnamara et al. (2014), deliberate practice was able to explain 61 % of the variance in performance level for games, music, sports, education, and professions, compared to the 14 percent of explained variances for all these areas in the original meta-analysis. Furthermore, Debatin et al. (2021) argues that estimated effect sizes for deliberate practice have been underestimated due to the neglect of individualization of practice. In their study, they highlight the importance of individualization of practice where the differences in quality of practice, availability of individualized informative feedback, and diagnosis of errors is a key component to explain differences in levels of performance. The same study showed that when there is a high level of individualization and quality of practice, the effect of size is three times higher compared to average level of individualization and quality of practice. They conclude that effect sizes for deliberate practice have been underestimated due to this, and the question of how much performance level is influenced by deliberate practice remains open. Furthermore, Ericsson (2008) argues that what makes deliberate practice different from regular practice is that it requires active engagement, practice designed and led by an expert coach where the focus is on improving specific skills, immediate feedback after performance, time for problem-solving and evaluation, as well as opportunities for repetition of performance to improve and refine behavior. Moreover, in a meta-analysis by Platz et al. (2014), they examined the effect of deliberate practice on musical achievement and found a very high correlation between the two variables (r = .61). In fact, more coach-led practice early on in an athlete's career does lead to higher levels of performance during their junior careers (Güllich et al., 2022). However, it does not correlate with performance level at the senior level. Lastly, Coutinho et al. (2016) concluded that both early specialization and early multi-sport engagement within sports participation can lead to expertise development.

Individual differences in practice

It has been suggested by Miller et al. (2020) that deliberate practice as training method should be seen as a potent and reliable way of improving performance. When it comes individual differences in athletes practice, Coughlan et al. (2014) compared expert and intermediate gaelic football players and found that experts rated their practice as more effortful than the intermediate group, highlighting the difference in how experts and intermediate level performers practice. Moreover, it was also concluded by Baker and Young (2014) in a review of deliberate practice research that there are clear differences in practice behaviors between experts and novices, further arguing for the theory of deliberate practice that the reasons why experts become experts is due to their amount of accumulated deliberate practice compared to novices. Furthermore, in a study by Coughlan et al. (2019), they compared kicking accuracy for gaelic football players in an intervention group and a control group where they manipulated the intervention group to increase mental effort. This led to a significant increase in the measured performance variables compared to the control group, highlighting the effect of applying deliberate practice principles. These results indicate that even though deliberate practice has received plenty of criticism, designing practice using the principles of deliberate practice, can lead to improvement in performance variables. However, Baker and Young (2014) have argued that even though deliberate practice has been shown to have a critical role in expertise attainment, there is not enough evidence to conclude casual relationships between engagement in deliberate practice and level of attainment due to the limitations in study designs. They also argue that studies usually include measuring accumulated deliberate practice though retrospective techniques, and these studies are not able to include control groups and have follow-ups with dropouts of the development system. There is evidence to support early specialization and deliberate practice to help improve performance and achieve expertise in sports. However, Tucker and Collins (2012) conclude that deliberate practice has an important role in highlighting differences in elite performance, but deliberate practice by itself cannot produce elite level performers. There is a need for research to explore different methodological approaches that may help explain more of what makes an expert performer.

Linear pedagogy

In traditional learning models, all learners usually complete the same exercises that progress from simple to hard, and implies a linear causality were spending more time doing certain exercises will lead to more improvement of a particular skill (Schöllhorn et al., 2012). The assumptions of linearity in practice are that you break up specific sports movements into a specific stage or bodily focus that are then trained separately, and then put together to complete the whole movement. In summary, the traditional learning method promotes the idea that to learn, one should repeat a particular movement as much as possible, while receiving performance feedback from an expert. This is in direct line with the theory of deliberate practice, where the idea is that an athlete should complete as many hours as possible of effortful and purposeful practice to reach an expert level of performance (Ericsson, 2008). Moreover, the assumption is that the coach prescribes an ideal way of performing a skill that applies to everyone, and to deviate from the ideal way of performing that skill is seen as an error (cf. Schöllhorn et al., 2006). In contrast to the traditional learning method, Bernstein (1967) discovered that movements that appear to repeat themselves, do not. Bernstein was able to show through cyclograms that expert blacksmiths who swung their different tools to shape different objects never repeated the same swing twice, and the movements were always slightly different. This has later also been shown to be true in sports like discus and javelin, that in fact there is high variability between and within athletes in their techniques (Schöllhorn, 2000; Schöllhorn & Bauer, 1998). Schöllhorn (2000) even showed that the elite discus throwers did not produce the exact same throw twice during a one-year period. Furthermore, Zheng et al. (2008) compared pro and amateur golfers and found significant differences in several different factors related to their swing using a motion tracking system. From a deliberate practice standpoint this is exactly what is predicted. The experts should be using different techniques compared to amateurs because they are expert performers that have put in thousands of hours of deliberate practice. They also calculated the average degrees certain body parts would have at certain points during the swing. From a traditional learning model perspective, one could take the average degrees that body parts of the pro golfers had during certain points of the swing and use them to model the one correct technique. However, what is also seen in the data is that every golfer varied in their techniques since the study did not report a standard deviation of zero for each average degree certain body parts had at certain points during the swing. Not every pro golfer used the same technique, and they all played on the Professional Golfers' Association (PGA) tour. Some pro golfers had larger angles for certain body parts at certain points during their swing, than did other pro golfers. If there was such a thing as the one correct way to move, then we would have seen the pros use very similar techniques were the inter-variability in technique was very low. However, this is not what Zheng et al. found.

Ecological dynamics and non-linear pedagogy

In contrast to the idea about linear progression of skill acquisition, the theory of ecological dynamics is based on non-linear pedagogy that assumes that cognition, perception, and action are three elements in skill acquisition which are tightly intertwined and should not be separated and trained independently of each other (Chow et al., 2015). Put simply, in non-linear systems, small psychological or physical changes to an individual can have large effects on performance, and large changes in the system can also have minor effects on performance (Chow et al., 2011). Moreover, in linear systems, a large change will result in a large effect on performance, and a minor change will result in a minor effect on performance. Another key difference between the two systems is that in linear systems, a single change to an individual can only result in a single behavioral effect, compared to the non-linear system where a single change can cause multiple behavioral effects. This leads to a third difference, which is *parametric control*. Since single changes to a system can have multiple effects in non-linear systems, coaches can guide athletes to explore different solutions and explore the functionality of different behaviors. Through parametric control, coaches can help expose the athletes to possible task variability that they can encounter, in order to learn which behaviors are functional and which are not when the athlete must adapt to the environment and task constraints (e.g., rules of the sport, size of playing field, equipment). Lastly, linear and non-linear systems differ in how they view the role of noise in the system. In a linear system, noise is defined as uncontrollable and is detrimental to performance output since it creates undesired system variability which leads to inconsistent outputs. Compared to linear systems, in non-linear systems noise has a functional role because it increases the chances of the system switching between different functional states. The idea is that noise will work as signal variability that will help the athlete explore several different solutions to a behavioral goal, and to help create a more flexible athlete.

In non-linear pedagogy, it is the goal to promote an increase of what is called degeneracy (Lee et al. 2014). Degeneracy is the ability to achieve the same outcome in many ways. Having a larger degree of degeneracy allows the athlete to solve different environmental demands put on them during competition in many different ways, and still reach a consistent successful outcome. It could be said that the promotion of degeneracy increases the variance of available movement solutions to a given environmental demand for an athlete, but decreases the variance of the outcome because it allows the athlete to apply the best possible solution to successfully solve a specific environmental demand, and achieve the same end result. Furthermore, Lee et al. showed that a nonlinear pedagogy approach for learning sports skills in tennis was an effective method for increasing degeneracy within the individual athlete. Other studies have also shown that non-linear pedagogy can be effective in improving individual and team performance in sports (Pizarro et al., 2019; Práxedes et al., 2019). Moreover, using a coaching curriculum based on non-linear pedagogy has been shown to be more effective for certain skills in youth sports than a linear approach (Ghorbani Marzoni et al., 2021; Nathan et al., 2017; Práxedes et al., 2018; Roberts et al., 2020). The linear approach in the studies was characterized by the training being led by an expert coach that prescribes an ideal movement solution, and training repetitively in environments that are predictable to achieve consistent movement outcomes. However, research has also shown that both linear and non-linear approaches can positively influence skill development (Lindsay et al., 2022; Mousavi et al., 2019; Valeh et al., 2020).

Non-linear pedagogy and the theory of ecological dynamics proposes that the emergence of behaviors happen because of how an innumerable number of constituents of the body interacts, to create a complex adaptive system that does not include a central control unit deciding which behaviors or movements to learn (Chow et al., 2011). The relationship between the individual and environment in which they perform, is crucial for how the behavior of the athlete adjusts and self-organizes their own solution. Furthermore, it is suggested that self-organization of certain behaviors for an athlete will arise in specific situations as a consequence of the interaction between different constraints in the form of individual constraints (e.g., personality traits, height, weight, genetics), environmental constraints (e.g., visual and auditory information, competing indoor or outdoor, conditions of the playing field, weather), and task constraints (e.g., rules of the sports, equipment, number of players, playing area). Moreover, it is through the interaction of these constraints, that a bottom-up process is created where the cognitive processes by each individual will create differences in how the individual, environmental, and task constraints affect the emergence of different movement patterns.

Affordances and embodied perception

Chow et al. (2015) proposed that the learner will perceive affordances for action depending on the constraints in the environment and internally. Furthermore, it is thought that the combinations of constraints over time is what create individual differences in which goal-directed behaviors are afforded the athlete in particular situations and can lead to non-linear learning effects of the performer. This is what is known as affordances, and they are both objective and subjective, or neither, because the perception of environmental cues will be perceived differently depending on the individual (Scarantino, 2003; Turvey and Shaw, 1999). For example, when a person must go from walking to running on a treadmill when the speed is successively increased, at some point the person will reach a critical point in which they must go from walking to running. Furthermore, the interaction between the individual constraints (leg length, muscle strength, walking ability, running ability) and the speed of the treadmill will create a demand for a change in stride length to stay on the treadmill (Chow et al.). The affordances presented to an individual will be perceived uniquely within their own frame of reference, no matter if the individual is an elite-athlete, a novice, an adult, or a child, because they will always be specific to the individuals' body morphology and the particular movement solutions that it enables (Seifert et al., 2016). Moreover, this is also predicted by the theory of embodied perception, where it is theorized that individuals will perceive the scale of objects in the environment differently depending on their own ability to interact with that object (Gray, 2014). In fact, when it comes to embodied perception, several studies have found evidence to support this theory in the context of sport. Furthermore, perception has been shown to be influenced by different types of action-related variables such as current performance level (Cañal-Bruland et al., 2010; Gray, 2013; Lee et al., 2012; Witt & Dorsch, 2009; Witt & Proffitt, 2005; Witt & Sugovic, 2010), difficulty of the task (Gray, 2013; Witt et al., 2008; Witt & Suguvic, 2010), and the goal of the task (Gray, 2013). Lastly, embodied perception highlights some key differences between individuals when it comes to their perception of their environment depending on these three variables (Gray, 2014).

In sports, there is a need to help athletes learn skills that will allow them to solve and adapt to dynamic environments that are constantly changing, uncertain, and complex (Chow et al. 2011). This creates a demand to develop pedagogical frameworks that: (1) simulate conditions during competition in practice and drill, (2) challenge the athlete to practice in representative environments, (3) provide athletes with high variability during practice to improve their ability to adapt, and (4) help the athletes become independent of continuous feedback, guidance, and instructions. In fact, research has shown that skill acquisition methods in sport based on the theory of ecological dynamics have the potential to be more effective pedagogical tools than traditional learning methods (Clark et al., 2019; Tassignon et al., 2021).

Practice variability

Traditional learning methods based on deliberate practice and linear pedagogy have tested different methods for achieving different levels of practice variability. For this, Schmidt (1975) proposed his theory of discrete motor skill learning. Schmidt's theory proposes that when an individual is presented with an initial condition, that same individual uses a recall schema to come up with a movement to produce, and a recognition schema to determine the correctness of the response. The theory predicts that there will be a positive transfer of skills from practice to novel situations like those in competitions when similar tasks like those in competitions are practiced in combination with variations of these tasks. Furthermore, *Contextual interference* is the degree to which conditions are varied within tasks (Shea & Morgan, 1979). Practice where conditions have low contextual interference are characterized as *blocked*, and practice where conditions have high contextual interference are characterized as *random*. Blocked practice focus on repeating the same movements through repetition, to achieve a consistent movement that results in a consistent outcome. Random practice will vary the condition from rep to rep. Research in traditional learning has compared the degree of contextual interference with motor learning and transfer of skills to competitive settings. Blocked practice has been showed to increase motor learning for specific practice tasks more compared to random practice, but random practice has at the same time been shown to facilitate better motor learning and transfer of skills to competition settings that do not mimic those during practice compared to blocked practice (Goode & Magill, 1986; Holladay & Quiñones, 2003; Rohrer & Taylor, 2007; Shea & Morgan, 1979; Ste-Marie et al., 2004). Moreover, in a meta-analysis by Brady (2004), it was shown that the effect of using blocked, random, or a mix between blocked and random on retention of skills and transfer of skills tests for applied research conducted in a field setting with typical sport skills was small (d = .19). This means that studies that have been conducted in applied settings using either random, blocked, or a mix between blocked and random had a combined small effect on the retention of skills trained in those ways, and on the transfer of skills to new settings. Brady also showed that both age and experience strongly mediated the effect of variability of practice, where it was shown that variable or random practice was less beneficial for new learners. However, in a very recent meta-analysis by Ammar (2023), they found no evidence that methods based on contextual interference have any effect in sports settings. They further showed that how practice is designed or structured has no effect on performance tests examining skill acquisition, retention, and transfer. These results bring the generalization of contextual interference in sports settings into question, and they recommend that alternative motor skill learning methods be evaluated.

Differential learning

One pedagogical method within ecological dynamics is differential learning (DL). The DL approach involves guiding of the learner through manipulation, and the goal is to de-stabilize an existent movement solution by changing the individual fluctuations in order to promote a way for the learner to self-organize to a new, and better movement solution (Schöllhorn, 1999). This is done through a process called *stochastic resonance*, and in the theory of DL it is proposed that through the addition of variability during practice, performance can be improved. Stochastic resonance involves amplifying the athlete's current inherent variability, by adding random perturbations to the practice environment. Therefore, when applying DL in a practice session, the changes made in practice conditions should promote random, additional, and irrelevant movement components that is most likely never going to be used during competition by the athlete. Given the discoveries that indicate that movements do not repeat themselves and that there are several ways to achieve successful results (Bernstein, 1967; Schöllhorn, 2000; Schöllhorn & Bauer, 1998; Zheng et al., 2008) and the theory of ecological dynamics, Schöllhorn et al. (2006) suggest that it would seem logical that we not adhere to the dichotomous view of wrong and correct performances, but rather should consider these as different levels of fluctuations around a pattern of stability. Moreover, Tassignon et al. (2021) reviewed the empirical evidence of differential learning as a method to improve motor learning and found that DL has the potential to result in better average improvements compared to more traditional and non-variable practice methods. However, they also pointed out that the current empirical evidence is not strong enough to conclude that DL is a better method because of the limited number of studies that have tested the effects of DL, and they have had low sample sizes, and low statistical power. Therefore, it would be premature to conclude that DL is a better motor skill learning method than a more traditional, blocked, and non-variable practice method (Tassignon et al.). Schöllhorn et al. (2006) proposed that some of the advantages of using a differential learning approach is that differential learning is assumed to utilize the inherent self-organizing process in each movement system that can help guide an athlete towards the ability to respond effectively to new situations in a shorter time. Moreover, Schöllhorn et al. (2009) suggested that in DL, promoting movements which are not likely going to be repeated in competition environments because they simply are not very efficient or optimal in any situation, is what will help the athlete self-organize into new and improved solutions. Furthermore, varying different parameters and randomizing the order in which you present these varied instructed solutions to the athlete will help cover a large potential space of solutions. The idea is that when the solution space is being covered with different solutions which are not optimal for competition, the optimal solution for the athlete will become more salient, which can be seen as a weak signal which have not yet been discovered by the athlete and will be strengthened by covering the space around it.

What is then the optimal degree of random perturbations then? The answer to this question remains unclear to this day (Schöllhorn et al., 2006; Schöllhorn & Horst, 2019). However, Schöllhorn et al. (2009) proposed a hypothesis that the optimal level of random perturbations could be determined by the skill level of the individual. This is because beginners tend to have fewer stable movements from repetition to repetition causing a larger variability in movement variation from task to task. Beginners inherently have a higher level of randomness in movement compared to more veteran performers who inherently have a lower level of randomness in the movement. Therefore, it is suggested that you could vary the degree of random perturbations based on skill level and use less random perturbations for beginners compared to veterans. However, it is still recommended that an individualistic approach is applied to deciding what degree of random perturbations is needed for optimal learning and progression of skill acquisition (Schöllhorn et al., 2009). Moreover, the degree of random perturbations added should be relative to the level of inherent variability there is in a movement. It can be challenging for coaches and practitioners to apply DL and find the optimal degree of random perturbations since every single individual will have their own optimal degree of this because they will differ in many ways. However, Tassignon et al. (2021) proposes that the addition of random perturbations seems to result in increased learning in many different sports.

There is clearly a need to test more traditional learning (TL) approaches and pedagogy to ones that do not assume that there is one optimal way for all athletes to replicate exactly. Previous research has compared the effects of a DL approach and a TL approach within several different sports (Tassignon et al., 2021). However, there are no known peer-reviewed studies that have made any direct comparisons between a TL approach and a non-linear pedagogical approach within the sport of American football, or tested any effects of a non-linear pedagogical approach to teaching motor skills within the same sport.

The wide receiver stance and start

In American football, the wide receiver is one of the positions a player occupies on the field. According to professional American football coach Jay Norvell (2013), "*receivers are the perimeter weapons who attack the field both vertically and horizontally in the passing game*" (p. 2). According to Norvell, part of the job of a wide receiver in the passing game (part of American football where the ball is being thrown forward) is to get to a particular spot on the field at the proper time, and to accomplish this the receiver needs to be in a proper stance that will allow the athlete to accelerate as fast as possible when the play starts. This study will define an optimal wide receiver stance as one that allows the athlete to accelerate as fast possible after the play starts. Part of the wide receiver stance and start is to react to the initial movement of the ball by the center, called a snap. As soon as the ball is snapped by the center, all offensive players, including the wide receivers, are allowed to move. Therefore, to improve the stance and start of a wide receiver, improving the reaction time of the snapped football would be part of this process.

In a study by Savelsbergh et al. (2010), they examined the effects of teaching a speed skating stance to one group of participants using a TL approach and another group using a DL approach. This is the only known study that has tried to improve a stance and start in sports using a DL approach, while also comparing it to effects of using a TL approach. Furthermore, the study showed that the DL group had improved their speed skating start and speed over a 50-meter distance compared to a control group. Beyond this finding, both TL and DL approaches improved speed skating stance and start to novices, showing that the DL approach has merit.

Approaching the stance and start of a wide receiver through the lens of a traditional learning method, there should be one correct way to perform the entire action and any deviations from this ideal way would be considered an error. The way that Norvell (2013) instructs how to teach the wide receiver stance and start is in line with a TL approach. For example, in the stance and start for the wide receiver, a step with the front foot in any direction before a forward linear movement by the wide receiver is considered a false step by Norvell. According to Norvell, this false step needs to be eliminated because it takes time and makes the wide receiver take longer time to get to his designated spot on the field in proper time. It is not clear whether his prescribed ideal way of a stance and start for a wide receiver is based on anecdotal evidence from his experience as a professional American football coach, or whether it based on scientific peer-reviewed studies. However, using a false step to improve sprint performance has been shown to improve sprint times over short distances of 2.5 and five-meters (Frost & Cronin, 2011). However, this study did not use any interventions to teach the participants of the study to use a particular start procedure to improve their sprint time. Furthermore, in a study by Cronin et al. (2007), they found that there were no differences between using a start that included a split stance where one foot was back and the other in front when using a false step and when not using a false step. Also, in a study by Knudsen and Andersen (2017), sprint times of wide receivers were examined using 3 different techniques, (1) no false step, (2) backwards false step, and (3) forwards false step. 11 American football players were instructed to perform 12 five-meter sprints using the different techniques in a random order. Overall, the no false step was shown to have the fastest time, and the backward false step was significantly slower than the no false and forward's false step. This study did not perform any interventions, or any pre and post-test, and had a very small sample size. In both studies by Cronin et al. (2007) and Knudsen and Andersen (2017), it is unclear whether there is a potential bias for one of the techniques which Knudsen and Andersen (2017) also point out in their study. Moreover, using a study design that includes a randomization of groups and pre and post-test before and after a potential intervention, would help increase the validity of a study that examines whether a technique that includes a backwards or forwards false could be taught to make a wide receiver sprint faster on short distances. The results of studies by Frost and Cronin (2011), Cronin et al. (2007) and Knudsen and Andersen (2017), brings up the question of whether there is one ideal way for a wide receiver to stand and start which could be taught, or if a more individualized approach that allows the individual wide receiver to self-organize a solution based on their own individual constraints to maximize their stance and start.

Aims of the present study

The aim of this study is to compare the effects of a traditional learning (TL) approach and a DL approach in American football. The study will compare the effects of a physical intervention program where one group will be taught the stance and start for the wide receiver position through a TL approach, and the other through a DL approach. This study aims to answer the questions of whether there are more effective learning methods than the dominating TL approach within the sport context, and in this case American football. The intervention involves teaching a wide receiver stance and start to increase sprint times at five-, 10- and 20-meters. The groups will be randomized based on age and number seasons of experience playing the position of wide receiver in American football to control for expected effects on performance learning. Based on previous findings of the effects of DL on performance variables, the experiment was designed to test the following hypothesis.

Hypotheses

H1: All participants will improve their sprint times from pre- to post-test for all distances, regardless of training group.

H2: The DL training group will have a larger improvement in sprint times compared to the TL group for the distances of five-, 10- and 20-meters.

H3: Experience, Age, and Rate of Attendance will covary with the differences in pre- and post-times for all distances.

Method

Participants

There were 35 participants that initially partook in the study, but only 28 completed all parts of the study. The inclusion criteria for participating in the study was that the participants were between 13 and 17 years old. No prior experience playing the sport or as a wide receiver was necessary to participate in the study. Some participants got injured either during their regular practice time or during non-practice time, and therefore had to drop out of the study. Other participants were not able to attend the post-test. These 28 had been assigned to either the TL (n = 14) or the DL (n = 14) group. The mean Age in the TL group was 15.1 years (SD = 1.03) and 15 years (SD = .96 years). All the participants were male. The mean Experience in the groups were .5 seasons (SD = .76) in the TL-group and 1.07 seasons (SD = 1.73) in the DL-group. Lastly, the average Rate of Attendance in TL-group was 71 % (SD = 18) and 79 % (SD = 18) in the DL-group. One of the participants in the TL-group was removed from the final sample (N = 27) due to him being an outlier according to boxplots of the different sprint distances. This was done to avoid any spurious outliers (Fein et al., 2022).

Apparatus and materials

Three cameras consisting of two smart phones and one video camera were used to measure the times it took participants to run the three distances. The participants' sprint times were recorded by filming the participants from the neck down to preserve anonymity. A short survey was created which asked the participants for demographic information (name and age) and the number of seasons of experience playing the position of wide receiver. The survey also contained a section where participants gave their consent to participate in the study.

Procedure

Participants were first asked to fill out the survey portion of the experiment and give consent to participate. Subsequently, all consenting participants completed a pre-test, measuring the time it took to run five-, 10- and 20-meters (an illustration of the setup for the pre- and post-test can be found in appendix A). In the instructions to the participants for the pre- and post-test, they were asked to align in a wide receiver stance of their own choice and run as fast as they could as soon as they saw that the center snapped the ball backwards. Two tries were recorded for each participant and the fastest of the two times was recorded as their pre-time. Participants' age and previous wide receiver playing experience was then used to randomize which intervention (DL or TL) that they would receive. This was to make sure that the groups had similar Age and Experience to minimize group differences and possible effects related to these variables. Each group completed seven training sessions where either a TL or DL learning method was applied when teaching the wide receiver stance and start. Each training session took approximately 10 minutes to complete. The DL group would start their training session after the football team had warmed up, and after they had completed the session, the TL-group would complete theirs. After the seventh training sessions, participants were asked to perform a post-test exactly like the pre-test. The participants were given the exact same instructions as in pre-test, and each participant were allowed two trial runs. After the times of sprints had been recorded, the participants were allowed to find out their pre- and post-test times if they wanted to.

Data collection for pre- and post-test

When converting the video recordings of the pre- and post-test sprints, time stamps in the video would be made for when the ball was seen starting to move backwards, and when the chest of the participant crossed the distance that the given camera was aligned at. The start time stamp would be subtracted from the finish time stamp. The fastest time out of the two trial sprints in the pre-test would be chosen as the participants official pre-test sprint time, and the same would be for the post-test sprint time. Some participants recorded a faster five-meter time in one trial run compared to the other, but at the same time a slower 10- or 20-meter time in that same trial. In this case, the run with the largest time difference was the one chosen as the best time, and the one to be analyzed. For example, if a participant had a five-meter time of 1.59, a 2.30 10-meter time, and a 20-meter time of 3.80 in one run, and in the other had a five-meter time of 1.60, a 2.30 10-meter time and a 20-meter time of 3.75, then all the times from the later run would be recorded as the participants best run since the first run had a .01 time difference for the five-meter time, but a .05 time difference for the second trial’s 20-meter time. Since .05 is larger than .01, the second run would be recorded as the best completed run by the participant.

Traditional learning group intervention

In the TL group, the participants were taught a wide receiver stance and start based on the one described by Norvell (2013). In appendix B, a detailed description of the stance that was taught in TL group can be found. The intervention for the TL group completed seven intervention sessions where each participant completed 20 five-meter sprints while receiving instructions to align in a stance according to Norvell. Corrective feedback regarding the performance of the participants was given when they did not align according to Norvell. For example, if a participant did not bend his knees as much as described in Norvell, then that participant would receive corrective feedback from the experiment leader in form of instructions to bend his knees more until the desired bend was reached. A detailed diagram of the training session setup that was used during the intervention can be found in appendix C. During the training session, the experiment leader gave the instructions and feedback to players in line with the TL method. The setup used during the training sessions can be found in appendix C. After the training session, attendance of the participants who had participated in the practice that day was noted for the rate of attendance among the participants.

Differential learning group intervention

In the DL group, the participants were taught a wide receiver stance in line with the DL theory. Participants in this group received instructions to align in wide receiver stances that would never be used in a competitive setting. The stances that the participants were instructed to align in can be found in Appendix D. Every instructed stance was unique and was never repeated during the entire intervention. No feedback was given regarding the performance of the participants. A detailed diagram of the training session setup that was used during the intervention can be found in Appendix C. After the training session, attendance of the participants who had participated in the practice that day was noted for the rate of attendance among the participants.

Variable selection

The variables that were collected during the study were the following: Age, Experience, Rate of Attendance, sprint times for five-, 10- and 20-meters at pre- and post-test, and the change in sprint time from pre- to post-test. Experience was defined as how many seasons a participant had completed where they had played in at least two games as primarily a wide receiver. Participants who had only played a single game, or only part of a game as a wide receiver had therefore not accumulated a single season of experience playing the position of wide receiver. Attendance during the intervention was noted for all participants. The Rate of Attendance was calculated by dividing the number of attended training sessions by the total number of training sessions scheduled (i.e., seven training sessions). The sprint times for five-, 10- and 20-meters were defined as the time it took a participant to run from the starting position in a straight line to the measured distances. The variables collected from the pre– and post-test times for five-, 10- and 20-meters, resulted in six sprint times. The final variable collected was the change in sprint time from pre- to post-test. This variable measured the potential improvement or decline in sprint times from pre-test to post-test. This variable was recorded by subtracting the sprint times of the post-test from the sprint times at the pre-test, such that a positive number corresponded to an increase/decrease in performance.

Ethical considerations

When it comes to potential risks of harm to the participants in the study, the physical intervention of the study was deemed to be similar enough to what the participants might normally be subjected to during a normal training session with their team. Therefore, it was decided that the study would follow the ethical guidelines established by the Swedish authorities. Also, the filming of the participants was done so that no faces could be seen on the tape later on. This was done to limit the personal data collected during the study. All participants provided signed consent before taking part in the study.

Results

The analysis was divided into three statistical tests based on the three different distances that were measured in the experiment. The dependent variable in all three tests were the pre- and post-test times (See table 3 for descriptive statistics for all distances and times). A Repeated Measures (RM) ANOVA was run for each distance with Time (pre- and post-test time) as the repeated measures factor, Group (DL and TL) as the between subjects factor, and Age, Experience, and Attendance as covariates. The first hypothesis was that all participants will improve in their sprint times at each time interval (five-, 10-, and 20-meters) and in order to support this hypothesis the analyses should result in a significant within subjects effect of

Time and/or any within subjects interaction effect. The second hypothesis was that the DL training group will have a larger improvement in sprint times compared to the TL group, which will be indicated by a within subjects interaction effect of Time and Group. Finally, to support the third hypothesis that Age, Experience, and Attendance, affects sprint times, significant within subjects interaction effects should be seen for any Time-covariate interaction.

Table 3

Descriptive statistics for all distances (five-, 10-, and 20-meters) and times (pre and post) by group (DL and TL)

Group - Distance	*M* Pre	*SD Pre*	*M* Post	*SD* Post
TL – five meters	1.73	.07	1.69	.09
TL – 10 meters	2.55	.12	2.51	.13
TL – 20 meter	3.98	.22	3.93	.22
DL – five meters	1.71	.12	1.64	.11
DL – 10 meters	2.49	.15	2.44	.14
DL – 20 meters	3.89	.23	3.82	.20

Note. M pre = Mean pre-test times. *M* post = Mean post-test times. *SD* pre = Standard deviation for pre-test times. *SD* post = Standard deviation for post-test times. TL = Traditional learning. DL = Differential learning.

In all three RM-ANOVAs the sphericity assumption was not violated because the assumption of sphericity is always met when the RM has only two levels. The first RM-ANOVA was run on Time (pre- and post-times for the five-meter distance) as the repeated factor, Group (DL and TL) as the between subjects variable, and with Age, Attendance, and Experience as covariates. Levene's test for homogeneity of variances was not significant ($F_{\text{pre five-meters}}$ (1, 25) = 1.44, p = .24; $F_{\text{post five-meters}}$ (1, 25) = .09, p = .77) and the Q-Q plot confirmed that the normality assumption was not violated. The RM-ANOVA analysis showed that the within subjects interaction effect between Time and Group was significant ($F(1, 22) = 7.49$, p = .01) and all other within subjects effects were not significant (see Table 4 for within subjects effects). A significant between subjects effect of Age was found ($F(1, 22) = 14.93$, p < .001) with all other between subjects effects being non-significant (see Table 5 for between subjects effects). A post hoc analysis with Tukey correction was carried out on the Time by Group interaction, revealing significant differences between pre- and post-times for the DL group (p < .001) and pre-test time for the TL group and post-test time for the DL group (*p* = .03), all other comparisons were not significant (see table 6 for all post hoc comparisons).

Table 4

Repeated Measures ANOVA within subjects effects for five-meter pre- and post-test times

	SS	df	MS	*F*	η^2g
Time	$6.30\text{x}10^{-5}$	1	$6.30\text{x}10^{-5}$	.07	< .000
Time * Group	= .007	1	= .007	7.49**	= .024
Time * Age	= .001	1	= .001	1.33	= .004
Time * Experience	$3.30\text{x}10^{-4}$	1	$3.30\text{x}10^{-4}$	.35	= .001
Time * Rate of Attendance	= .003	1	= .003	3.16	.01
Residuals	.02	22	$9.35\text{x}10^{-4}$		

Note. SS = Sum of squares. MS = Mean squares. Type 3 sums of squares. Time contains two levels where level 1 is the pre-test sprint times and level 2 is the post-test sprint times for the five-meter distance. α = .05. ***p* ≤ *.01*.

Table 5

Between subjects effects for five-meter pre- and post-test times

	SS	df	MS	*F*	η^2g
Group	.04	1	.04	2.96	.11
Age	.18	1	.18	14.93***	.39
Experience	= .005	1	= .005	.45	.02
Rate of Attendance	.03	1	.03	2.48	.10
Residuals	.27	22	.01		

Note. SS = Sum of squares. MS = Mean squares. Type 3 sums of squares. α = .05. *** *p* < .001.

Table 6

Post hoc test (Tukey correction) for the interaction between group belonging and change in sprint time from pre- to post-test.

Comparison		*M* Diff	SE	*t*-value (25)	*p*-value
Sprint time - Group	Sprint time - Group				
Pre-test - DL	Pre-test - TL	-.03	.03	-.89	.81
Pre-test - DL	Post-test - DL	.07	.01	5.98	< .001
Pre-test - DL	Post-test - TL	= -.008	.03	-.23	.99
Pre-test - TL	Post-test - DL	.10	.03	3.10	.03
Pre-test - TL	Post-test - TL	.02	.01	1.85	.28
Post-test - DL	Post-test - TL	-.08	.03	-2.50	.09

Note. DL = Differential learning. TL = Traditional learning. *M* Diff = Mean difference. SE = Standard error. α =.05.

For the five-meter distance, the results show that the DL group's sprint times decrease from pre- to post-test, but not for the TL group. Also, that controlling for the influence of other factors, the different Age groups had generally different times. The results thus show partial support for hypothesis one and two, but not for three.

The second RM-ANOVA was run on Time (pre- and post-times for the 10-meter distance) as the repeated factor, Group (DL and TL) as the between subjects variable, and with Age, Attendance, and Experience as covariates. Levene's test for homogeneity of variances was not significant ($F_{\text{pre 5 meters}}$ (1, 25) = .73, p = .40; $F_{\text{post 5 meters}}$ (1, 25) = .02, p = .89) and the Q-Q plot confirmed that the normality assumption was not violated. The RM-ANOVA analysis showed that the within subjects interaction effect between Time and Rate of Attendance was significant (F(1, 22) = 5.25, p = .03) and all other within subjects effects were not significant (see Table 7 for within subjects effects). A significant between subjects effect of Age was found (F(1, 22) = 9.93, p = .005) with all other between subjects effects being non-significant (see Table 8 for between subjects effects). A post hoc analysis through an estimated marginal means plot was carried out on the Time by Rate of Attendance interaction, revealing a negative relationship (See Figure 1 for marginal means plot).

Table 7

Repeated Measures ANOVA within subjects effects for 10-meter pre- and post-test times

	SS	df	MS	*F*	$\eta^2 g$
Time	5.28×10^{-4}	1	5.28×10^{-4}	.59	= .001
Time * Group	= .003	1	= .003	2.97	< .000
Time * Age	5.95×10^{-5}	1	5.95×10^{-5}	.07	= .001
Time * Experience	3.54×10^{-4}	1	3.54×10^{-4}	.39	= .008
Time * Rate of Attendance	= .005	1	= .005	5.25*	= .004
Residuals	.02	22	9.00×10^{-4}		

Note. SS = Sum of squares. MS = Mean squares.. Time contains two levels where level 1 is the pre-test sprint times and level 2 is the post-test sprint times for the 10-meter distance. Type 3 sums of squares. $\alpha = .05$. *$p < .05$.

Table 8

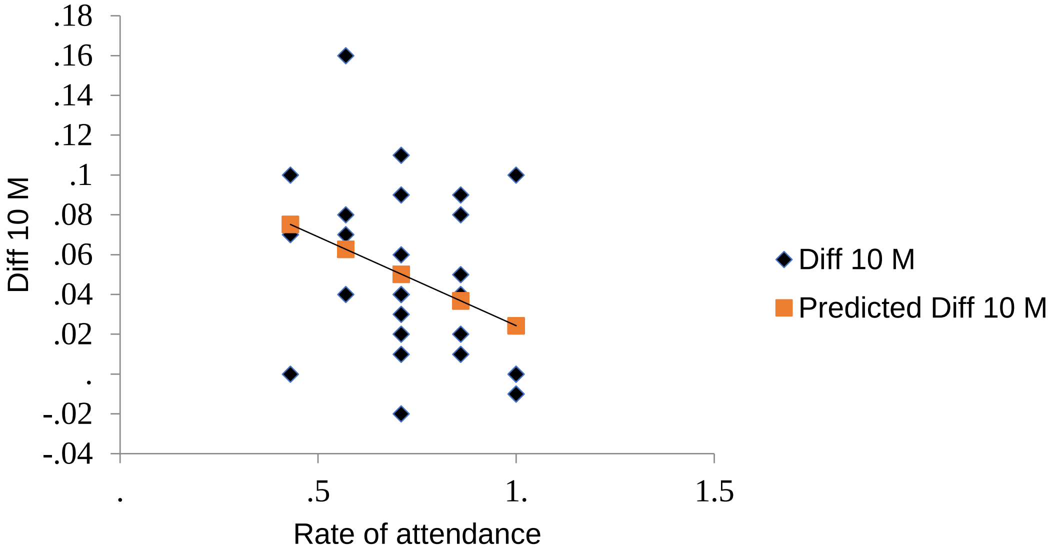
Between subjects effects for 10-meter pre- and post-test times

	SS	df	MS	*F*	$\eta^2 g$
Group	.10	1	.10	3.74	.14
Age	.27	1	.27	9.93**	.30
Experience	= .008	1	= .008	.31	.01
Rate of Attendance	.10	1	.10	3.56	.14
Residuals	.60	22	.03		

Note. SS = Sum of squares. MS = Mean squares. Type 3 sums of squares. $\alpha = .05$. ** $p < .01$.

Figure 1

Estimated marginal means plot for the interaction between Rate of Attendance and the change in sprint times from pre- to post-test



Note. Diff 10 M = Change in sprint times from pre- to post-test at 10 meters. Predicted diff 10 M is the estimated marginal means plot for the interaction between the change in sprint times at 10-meters and Rate of Attendance.

For the 10-meter distance, the results show that as the Rate of Attendance among the participants increase, the sprint time improvements decrease. Controlling for the influence of other factors, the different Age groups had generally different times. The results thus show partial support for hypothesis three, but not for one and two.

Lastly, the third RM-ANOVA was run on Time (pre- and post-times for the 20-meter distance) as the repeated factor, Group (DL and TL) as the between subjects variable, and with Age, Attendance, and Experience as covariates. Levene's test for homogeneity of variances was not significant ($F_{\text{pre 5 meters}}$ (1, 25) = .13, p = .27; $F_{\text{post 5 meters}}$ (1, 25) = .69, p = .41) and the Q-Q plot confirmed that the normality assumption was not violated. The RM-ANOVA analysis showed that the within subjects interaction effect between Time and Group was significant (F(1, 22) = 4.28, p = .05) and all other within subjects effects were not significant (see Table 7 for within subjects effects). A significant between subjects effect of Age was found (F(1, 22) = 6.20, p = .02) with all other between subjects effects being non-significant (see Table 8 for between subjects effects). A post hoc analysis with Tukey correction was carried out on the Time by Group interaction, revealing significant differences between pre- and post-times for the DL group (p < .001), all other comparisons were not significant (see table 10 for all post hoc comparisons).

Table 8

Repeated Measures ANOVA within subjects effects for 20 meter pre- and post-test times

	SS	df	MS	*F*	$\eta^2 g$
Time	= .004	1	= .004	2.62	= .002
Time * Group	= .007	1	= .007	4.28*	= .004
Time * Age	= .002	1	= .002	1.20	= .001
Time * Experience	= .003	1	= .003	1.62	= .001
Time * Rate of Attendance	9.87×10^{-4}	1	9.87×10^{-4}	.62	= .001
Residuals	.03	22	= .002		

Note. SS = Sum of squares. MS = Mean squares. Time contains two levels where level 1 is the pre-test sprint times and level 2 is the post-test sprint times for the 20-meter distance. Type 3 sums of squares. $\alpha = .05$. $*p \leq .05$

Table 9

Between subjects effects for 20-meter pre- and post-test times

	SS	df	MS	*F*	$\eta^2 g$
Group	.25	1	.25	3.14	.12
Age	.49	1	.49	6.20*	.22
Experience	1.97×10^{-4}	1	1.97×10^{-4}	= .003	< .000
Rate of Attendance	.16	1	.16	2.01	.08
Residuals	1.73	22	.08		

Note. SS = Sum of squares. MS = Mean squares. Type 3 sums of squares. $\alpha = .05$. $*p < .05$

Table 10

Post hoc test (Tukey correction) for the interaction between group belonging and change in sprint time from pre- to post-test.

Comparison		*M* Diff	SE	*t*-value (25)	*p*-value
Sprint time - Group	Sprint time - Group				
Pre-test - DL	Pre-test - TL	-.11	.08	-1.42	.50
Pre-test - DL	Post-test - DL	.07	.02	4.59	< .001
Pre-test - DL	Post-test - TL	-.10	.08	-1.18	.65
Pre-test - TL	Post-test - DL	.19	.08	2.34	.12
Pre-test - TL	Post-test - TL	.02	.02	1.46	.48
Post-test - DL	Post-test - TL	-.17	.08	-2.11	.18

Note. DL = Differential learning. TL = Traditional learning. *M* Diff = Mean difference. SE = Standard error. α =.05.

For the 20-meter distance, the results show that the DL group's sprint times decrease from pre- to post-test, but not for the TL group. Also, that controlling for the influence of other factors, the different Age groups had generally different times. The results thus show partial support for hypothesis one and two, but not for three.

The three RM-ANOVA yielded partial support for the hypotheses. The DL-group showed significant improvement from pre- to post-test for the five- and 20-meter distance, but not for the 10-meter distance. The TL-group showed no significant improvements from pre- to post-test for any of the distances. Age had a significant between subjects effect for all three of the distances, but only on differences between ages on the mean of pre- plus post-times. Rate of Attendance was the only variable included in the third hypothesis that was shown to have a significant interaction with sprint time in any of three RM-ANOVAs, and it was shown to have a negative interaction with sprint time for the 10-meter distance.

Discussion

The aim of the present study was to compare the effects of a linear (traditional learning) and a non-linear (differential learning) pedagogical method. The study investigated the if practicing the stance and start for a wide receiver in American football using these two different methods would improve the sprint times at five-, 10- and 20-meters. This was accomplished by recruiting 27 American football players from a local American football club and providing one half with DL training and the other half with TL training. The research question concerned the improvement of sprint times depending on the type of training received, controlling for variables such as Age, Experience, and Rate of attendance.

Out of the three hypotheses proposed, part of the first hypothesis that all participants will improve their sprint times from pre- to post-test for all distances, regardless of training group was shown to be statistically significant. Only the DL-group showed significant improvements from pre- to post-test at five- and 20-meters. For the distance of 10-meters, group belonging could not be said to have interacted with sprint improvements significantly even though it was close to also being significant (p = .10). However, for the distance of 10 meters, Rate of Attendance had a significant interaction with change in sprint time from pre- to post-test. The analysis showed that as Rate of Attendance increased, the lower improvements from pre- to post-test were made. The second hypothesis that the DL training group would have a larger improvement in sprint times compared to the TL group for the distances of five-, 10- and 20-meters was shown to be partly true since only the DL-group did make significant improvements from pre- to post-test (at five- and 20-meters), and the TL-group made no improvements. Lastly, the third hypothesis that Experience, Age, and Rate of Attendance will covary with the differences in pre- and post-times for all distances was shown to be partly supported. Rate of Attendance significantly interacted with the differences in pre- and post-times at 10-meters, but no other covariate significantly interacted with the differences in pre- and post-times at five-, 10- or 20-meters. Additionally, Age did have a significant effect on the sprint times independently of group belonging. However, this was to be expected since the Age range in the study varies over a time where body development is quite rapid.

The effects of differential learning

In line with previous research on the effects of differential learning, the DL-group showed significant improvements from pre- to post-test in sprint times. (Savelsbergh et al., 2010; Schöllhorn, 1999; Tassignon et al., 2021). The improvement of sprint times from pre- to post-test for the DL-group shows that designing practice based on the theory of DL can be an effective method for teaching sports skills. Furthermore, these results replicate the findings of Savelsbergh et al. (2010) which conducted a similar experiment, but with speed skating stance and starts. This shows that it is possible to apply DL methods to the context of teaching a motor skill in American football by promoting random, additional, and irrelevant movement components, and allowing the participants to self-organize a movement solution that fit them the best (Schöllhorn, 1999; Tassignon et al., 2021; Zheng et al., 2008). Moreover, the DL-group also received an intervention based more on a random design and using the idea of

Bernstein (1967) of repetition without repetition to improve performance. Furthermore, it was showed by Ammar et al. (2023) that blocked practice does not have any significantly better effect on skill acquisition than random. Therefore, not only has DL been shown to be an effective method in improving motor skills in previous research and in this study, but research also suggest that DL based on random practice design also has the added benefit of being able to transfer the practice of a given motor skill to a random and unpredictable environment, just like a game or competitive event (Chow et al., 2011; Chow et al., 2015; Tassignon et al., 2021).

The effects of traditional learning

In comparison to the significant improvements made from pre- to post-test in the DL-group, the TL-group showed no improvements at all for the different distances. This difference in performance highlights the potential that lies in applying a non-linear pedagogical method for skill acquisition. However, previous research suggest that TL-methods can be effective for teaching motor skills, and these results do not necessarily swing the argument for DL over TL (Coutinho et al., 2016; Debatin et al., 2021; Ericsson & Harwell, 2019; Platz et al., 2014). These results add to our understanding that DL as a method can also be applied to non-traditional sports like American football. To the best of the author's current knowledge there are no known studies that have compared linear and non-linear pedagogical methods within the sport of American football, and this study is the first known attempt to do so.

In the TL-group, the study applied a blocked practice design based on repeating the same movements as many times as possible to minimize movement variability to get a consistent result. This design applied a low level of contextual interference (the degree to which conditions are varied within tasks). The focus in the TL-intervention was on repeating movements over and over again in practice to produce a consistent and repeatable stance and start to produce a consistent and high-level performance outcome. However, in line with the recent meta-analysis by Ammar et al. (2023), no effect was seen for this level of contextual interference. Simply applying a given level of contextual interference does not seem to be enough to transfer skills from practice to competition. This study can be seen as a small contribution to current evidence highlighting the effectiveness of non-linear pedagogy and the inefficiency of linear pedagogical methods. However, just like Tassignon et al. (2021) pointed out, more research with higher sample sizes and greater statistical power is needed before one can make a strong statement of the generalizability of DL as an effective skill acquisition method.

Testing implications

The pre- and post-test applied in this study included a very simple and predictable task. The only element that was unpredictable in the test was the snap of the football, which allowed the participants to start their sprint. Normally in American football, a wide receiver is provided with a task to complete on any given play during the game when that person is on the field. Usually, the wide receiver is given around 20 to 30 seconds to take in the information on what task to complete and react to how the defense is trying to stop them from completing this given task. From an ecological standpoint, the test completed in this study did not mirror these competitive elements exactly. All participants were given ample amount of time to ask questions about the task and to see other participants complete the task before themselves. The stance and start of a wide receiver is part of many different motor skills that the athlete has to effectively utilize to reach a successful outcome. Moreover, an important methodological question for future studies trying to measure skill retention and transferability in the sport of American football, is to what degree the competitive environment is reflected in the actual test. Without this information it is uncertain whether transfer of training to a competitive environment occurs. Future research needs to consider how well the performance tests compare to the ultimate performance test, the games.

It is possible that the study would have seen different effects if the test deployed had been more unpredictable and representative of a random and game-like environment. One way this could have been done is if each participant had been assigned a specific route or pattern to run, and while running it, sprint times were measured at certain distances. Each participant would also not be told what route to run before it was their turn. This would have been more representative of a performance context for a wide receiver because of the switch between different route assignments for each play sequence. Furthermore, a more representative test that emphasizes unpredictability could have included a defender that would try to stress the athlete, without making contact with the participant. Combining these random and unpredictable elements would have created a more representative test of the skills of the wide receiver. However, researchers need to be careful not to include too many un-trained motor skills to the equation, since this might hinder the participants to highlight progress they have made on the trained motor skills. Henceforth, it is recommended that future studies analyze the performance environment from an ecological perspective to help researchers identify key attributes of the environment to include in performance tests (Chow et al., 2011). Also, using a representative testing environment would allow researchers to test whether a causal relationship between DL training and motor learning holds up to scrutiny, and to a larger degree be able to conclude that a transfer from training to competition has occurred for a given motor skill.

Testing a performance variable in a more random and unpredictable environment like a competitive situation would allow for the effect of degeneracy (i.e., the ability to achieve the same outcome in many ways) to come into play (Lee et al., 2014). In line with the theory of non-linear pedagogy, an environment where more than one solution is possible, just like in an actual competitive setting, athletes with a higher degree of degeneracy for a given environmental constraint would be able to reach a successful outcome more often than athletes with a lower degree of degeneracy (Chow et al., 2011; Chow et al., 2015; Lee et al.). Therefore, it is possible that designing more representative performance tests would allow training methods based on non-linear pedagogy to be able to better show the difference in effects between linear and non-linear methods.

The effects of the TL-interventions could possibly be limited by the level of engagement among the participants in this group. The idea behind deliberate practice is that one of the main things that makes deliberate practice (and its effects) different and better than regular practice is that it takes a high level of engagement in purposeful practice (Ericsson, 2008). Increasing engagement and mental effort in a practice activity has been shown to result in better performance outcomes (Coughlan et al., 2019). Therefore, it is possible that participants in the TL-group showed a lower level of engagement, and therefore showed a lower improvement in sprint times at five-meters. An important step for future research is to determine the importance of engagement in skill progression and performance improvement. By controlling this variable going forward, it would be possible to more accurately predict the effects that engagement might have.

Implications for Experience

Previous research from Brady (2004) and Ammar et al. (2023) concluded that Experience had a significant impact on contextual interference training methods, which was applied in the TL -group here. However, this study was not able to replicate the same findings. One of the reasons for this result might be that the degree of stochastic resonance that was applied in this study was not high enough. Previous research had suggested that the optimal degree of stochastic resonance should roughly match the level of Experience of the athletes which it is applied to (Schöllhorn et al., 2009). Furthermore, since Experience was not able to explain differences in improvements of sprint times, it is suggested that the level of stochastic resonance applied in this study did not reach a level that suited the participants' Experience level. More research is needed to confirm this, but the level of stochastic resonance used in this study can be used as reference point for future studies using DL-interventions in American football.

Implications for Rate of Attendance

The Rate of Attendance significantly interacted with sprint times for the 10-meter distance, but not for any of the other distances. Furthermore, the results showed an unexpected relationship between Rate of Attendance and improvements in sprint times. The interpretation of these results that the higher the attendance rate results in less improvements, is not in line with previous research on skill acquisition (Ericsson et al., 1993; Macnamara et al., 2014). This study of course has methodological limitations which will be discussed later on. However, an explanation for this might lie in non-linear systems. In non-linear systems, small changes or inputs can have large impacts, as well as big changes or inputs can have small impacts (Chow et al., 2011). Therefore, attending more training sessions does not necessarily have to result in a larger improvement of sprint times from pre- to post-test. Some individuals might need more training sessions, while others might only need one or two. Therefore, it could be expected that the correlation between Rate of Attendance and improvements in motor skill learning, could in fact be random. Some participants might improve is they attended more practices, while others might not improve at the same rate or even at all for some period if they attended the same amount practices as others. Moreover, Rate of Attendance also did not have a significant interaction with sprint times for five- and 20-meter sprint times, which might indicate that this is the case. Furthermore, some participants might only need a couple of practices to reap benefits to their motor skill learning. This particular result might point to the fact that this sample included a diverse set of individuals with different backgrounds, personalities, physical capabilities, and other internally dynamic traits. It would be meaningful for future research to start controlling for these variables in their samples, because it can be hard to compare samples between studies if we do not know how similar or different the individuals are. Also, improving sample size and choosing an optimal sampling strategy for participants will help provide a representative and normally distributed sample that will include individuals that will improve faster than others might to different training interventions.

Practical Implications

When it comes to designing a DL intervention, this study designed a simple and easy to execute training session which only needed two people to execute the training session. This study showed that DL has the potential to work in the context of American football, and that it is possible to design a short and simple task to execute during a training intervention to achieve significant improvements. However, there is of course a limit to how much can be generalized from the result of this study to other populations. The study would have needed a larger sample size, longer intervention and retention tests conducted after post-tests to see if the improvements are retained without the training or if it remains at the level of post-test, to increase the validity and reliability of the results. Furthermore, controlling for physical improvements like increases in strength and speed in a general setting would allow researcher to conclude that the improvements that are potentially made, are results of their intervention, and not the strength and conditioning program combined with the participants regular practice that has resulted in the sprint improvements. Nonetheless, even though there are plenty of factors to control for, this study was still able to design an intervention based on the theory of DL, and there was an improvement for the group that received it. Furthermore, the group that received the TL intervention did not see the same improvements in sprint times. This result should encourage more researchers and practitioners to investigate non-linear pedagogy and how it can be implemented practically. Researchers should also continue to compare linear and non-linear methods to conclude whether a method like DL might be better than the currently dominate skill acquisition model of deliberate practice and early specialization.

As of today, TL is still the most common and well-researched skill acquisition method, and practitioners should consider using both TL and DL methods when designing practice drills. It is still an open question whether DL outperforms TL, but at least there does not seem to be any evidence suggesting that DL is harmful or negatively impacts the skill acquisition of athletes. Practitioners should base their practice around scientifically proven training methods, but there is enough evidence to suggest that using DL for certain elements of training can be useful (Tassignon et al., 2021).

Incorporating more elements that align with non-linear pedagogy can give many benefits such as increased degeneracy, more individualized training for athletes, and help guide athletes to discover new and more optimal solution (Chow et al., 2011; Chow et al., 2015; Lee et al., 2014; Tassignon et al., 2014). The concept of increased degeneracy is one that most practitioners would in theory agree on is preferable, and if research can provide a proven better way to accomplish this then it will likely help shift the idea behind skill acquisition in sports today. Furthermore, research has also suggested that training methods based on non-linear pedagogy can help create a learning environment that fosters the intrinsic motivation of the learner (Araújo et al., 2020; Chow, 2013).

There is plenty of evidence to suggest a revolution in the way we think about skill acquisition, and how we design our practice to help our athletes develop skills to succeed.

Coaches and other practitioners should see this as a chance to evaluate their methods through a new and enhanced lens that is being pointed at areas we may not have thought of looking at before. This study and others suggest that it is worth evaluating our traditional methods and to test them to see if they are as effective as we may think, or if there are better ways of designing practice (Tassignon et al., 2021).

Limitations

There are some limitations regarding the generalizability of the DL intervention. The study did not control for general improvements in sprinting ability, and it is possible that the increase from pre- to post-test is a result of the players improving their physical capabilities in regard to sprinting as they were engaged in an off-season training program focused on that aspect. Furthermore, the study also did not control for Rate of Attendance and improvements in other physical activities such the teams conditioning or strength training sessions. Controlling for such confounding variables would be preferable to exclude such factors as having an impact on the change in sprint times from pre- to post-test. Furthermore, it is also unclear how engaged the participants were during the training sessions. Differences in engagement in an activity have been shown to explain differences in performance level. (Baker & Young, 2014; Coughlan et al., 2014; Debatin et al., 2021; Ericsson, 2008). Therefore, future research such control for the engagement when examining the effects of a DL intervention. Even though there are some potential confounding variables, the study did employ an ecological approach to teaching the stance and start of the wide receiver position through the TL and DL approach. The intervention was designed to be easily used by any coach, and realistic in the sense that most underfunded sports usually only have voluntary coaches who may not have time to control all of these other confounding variables in their practice. In this way, the intervention is very similar to how an actual voluntary coach might apply the principles of DL in their practice, and the intervention did see improvements in not just the TL-group, but also in the DL-group.

One limitation of the design of the study is the long-term effects on the retention of the skill. The intervention spanned four weeks and had the post-test the week after the seventh training session. Testing for retention of skills is a key element in evaluating the effectiveness of our pedagogical methods, and it is recommended that future studies try to test for the retention of the skills being taught in their intervention after some time has passed. Moreover, by incorporating several retention tests over a long period, it would be possible to see if there is a difference in how well skills are retained depending on the pedagogical method that was used to teach it. Furthermore, longitudinal studies that span several years, could provide key insights into the learning process that athletes may go through in their development when being subjected to a non-linear pedagogical method.

Conclusion

There is a clear argument to be made that there is a need for more research that tests and compares linear and non-linear pedagogy. Previous research and the results of this study further highlight the large potential that non-linear pedagogy has as a pedagogical method to use to help athletes self-organize new and optimal solutions that are degenerative and creative. This study, along with the previous research on DL highlight some revolutionizing ways to teach athletes different motor skills. However, while the approach holds a lot of promise, it is important to note that more research is needed to confirm its effects. More comparative research is needed to test different pedagogical methods against each other. There are also many unanswered questions when it comes to how to effectively employ DL in practical contexts. The revolution of skill acquisition is knocking on the front door, and it is an opportunity to explore.

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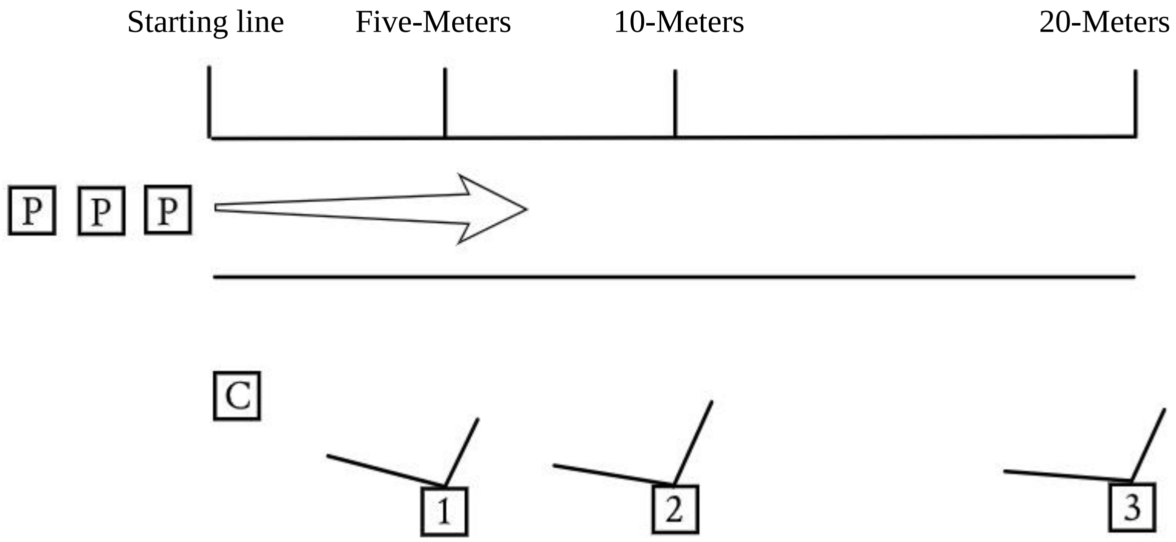
Appendix A

Pre- and post-test setup

Figure A1

Pre- and post-test setup



Note. Diagram of the pre- and post-test setup that was used to collect the data for sprinting times at five-, 10- and 20-meters. C = center. P = Participant. The arrow pointing away from the participants shows the running direction for the participants. Numbers one, two and three indicate the position of the three cameras filming the participants. The direction and area that the cameras are pointing at, and filming are being displayed by the v-shaped figures attached to the numbered boxes.

Appendix B

Traditional pedagogy approach for the traditional learning group

In the TL-group, the breakdown position is the stance that will be taught to the participants. The breakdown position is the body position that is being taught in Norvell (2013). A visual illustration of the breakdown position can be found in figures B1 and B2. To get into this position, the participants will be instructed to get into sprinters position seen in figure B3. To get into this position, the wide receiver should stand straight up with feet parallel to each other, then stagger the feet so that one foot is further back than the other, then bend the back leg knee down to the ground so that the knee is level with the heel of the front foot, and the position where the back foot hits the ground is where it should be in the ground when the athlete stands up. In this position, the wide receiver should keep 10 to 13 centimeters in width between the feet. From the position seen in figure B3, the wide receiver should get into the position seen in figure B1 and B2 by standing straight up. When the wide receiver is standing tall, they should bend the legs to be in crouch position where they are ready to go when the play starts. The weight of the feet should be on the balls of the feet so that the weight can be transferred through the legs into a vertical sprint. The hands should be up, and the shoulder pads should be low. To teach this, Norvell uses the phrase “high hands, low pads” (p. 54). This is to reduce the surface area for any opponent to hit and hold the wide receiver up on his path after the play starts. The upper body should be leaning over the front foot. Furthermore, the hands should be held high to be ready to be used against any opponent. For the weight distribution, the weight on the front foot should be 80 percent and 20 percent on the back foot. This is the model in which the athletes in study will be taught to align before sprinting.

Figure B1

The Breakdown position – Front view

Note. Breakdown athletic position: Feet staggered, weight on the ball of the feet, shoulders over toes, hands up and together

Figure B2

The Breakdown position – Side view

Note. Breakdown athletic position: Feet staggered, weight on the ball of the feet, shoulders over toes, hands up and together

Figure B3

The Breakdown position – Side view

Note. Breakdown athletic position: Feet staggered, weight on the ball of the feet, shoulders over toes.

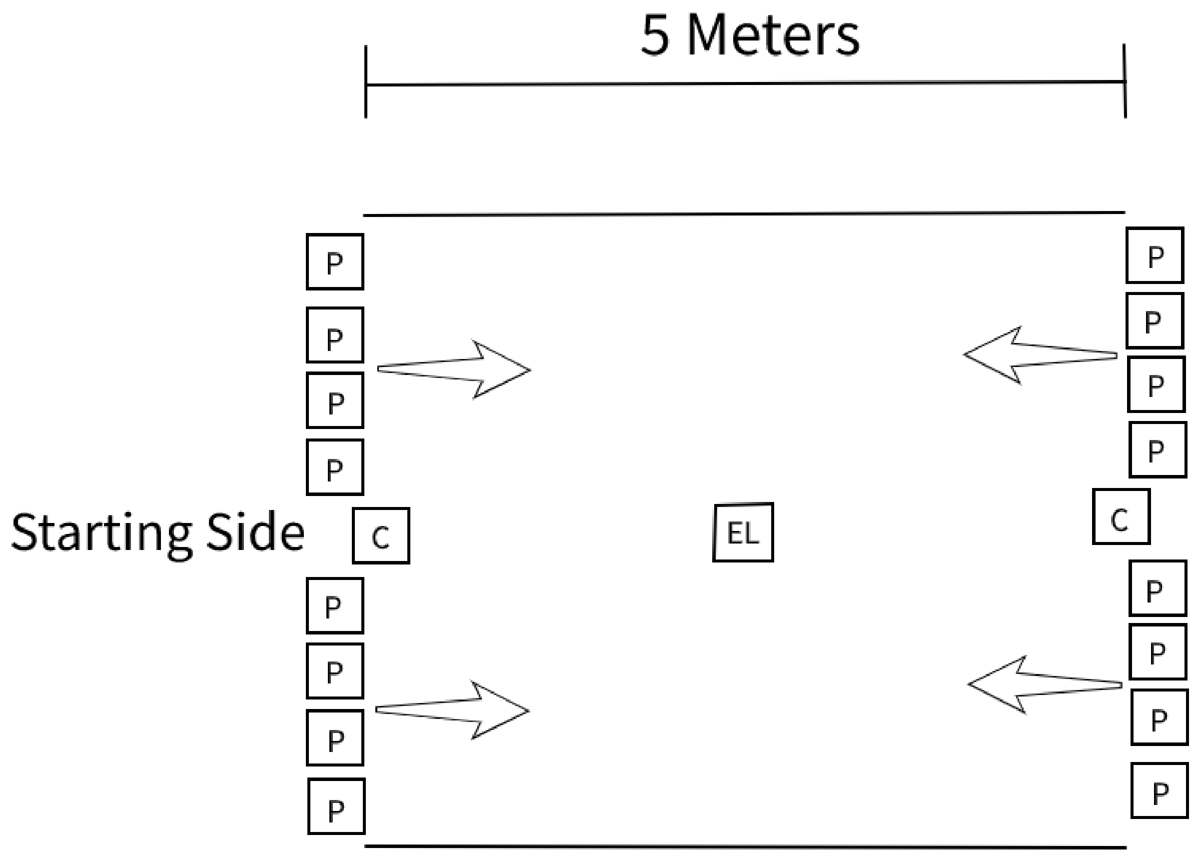
Appendix C

Intervention setup

The diagram for the training intervention setup for both groups in the study can be seen in figure C1. Participants (P) received instructions and feedback from the experiment leader (EL). The participants started on the starting side, and received instructions and feedback from the EL. After the participants had received instructions and feedback, the center (C) would snap a football backwards which signals the start for the participants to sprint 5 meters. When the participants had sprinted 5 yards, they turned around and again received instructions and feedback before aligning at the previous finish line and again started their sprint when the C snapped the ball backwards. This process repeated for 20 sprint repetitions in total.

Figure C1

Intervention setup



Note. P = Participants. EL = Experiment leader. C = Center.

Appendix D

DL Training intervention design

In the DL training sessions, the distance between the front and back foot would be based off starting with the back legs knee in the ground at the same level as the heel of the front foot. This distance between the front and back foot will be referred to as the sprinters distance. A visualization of this can been seen in figure B3 of appendix B. The participants would be asked to align their feet with either the sprinters distance, a distance shorter than the sprinters distance, or a distance longer than the sprinters distance. The participants would alternate which leg would be the front and back leg for every repetition. The weight distribution between the front and back leg was alternated between repetitions in the form of 50 % of the weight on the front leg and 50 % of the weight on the back leg, 70 %of the weight on the front leg and 30 % of the weight on the back leg, and so forth. The bend of legs would be based off the bend used in the TL approach and outlined in appendix B. This bend was referred to as a normal bend. The participants would either be asked to use this bend, less bend, or more bend. The participants could even be asked to have straight legs or even have their back leg knee just above the ground. The upper body lean would be based off the bend used in the TL approach and outlined in appendix B. The participants would either be asked to use this lean, more lean, keep their upper body parallel to the ground, straight upper body or slight lean. The position of the arms would alternate from different positions such as: Straight arm and pointing to the sky, straight arm and along the side of the body, elbows bent 90 degrees and the upper part of the arm along the side of the body, and several other arm variations were used. An example of a repetition during a DL training session could be to have a sprinters distance between the feet, left foot forward, 90 % percent of the weight on the front foot and 10 % on the back foot, slight bend of the legs, upper body parallel to the ground, arms straight out to the side, parallel to the ground and 90 degree bend in the elbow and with palms facing down.