THE EFFECT OF DIFFERENTIAL TRAINING ON LEARNING IN A STANDING BROAD JUMP

by

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ABSTRACT

This investigation examined the influence of two approaches of motor skill learning (differential learning and repetition-based) on the acquisition of a novel explosive motor task. Twenty-seven participants were randomly assigned to either a differential training ($n=14$) or repetition-based ($n=13$) group. All participants completed four training sessions consisting of either 20 variations (differential training) or 20 identical jump patterns (repetition-based) of the standing broad jump task. Pre-and post-training assessments were collected and included the recording of maximal jump distances and ground reaction forces. In addition to jump distance, a normalized vertical ground reaction force (GRF), rate of force development (RFD), and take-off velocity were computed to index jump performance. Survey data collected prior to training was used to analyze the effects of individual differences on training and consisted of correlating physical activity frequency and perceived skill level with performance variables. Results showed that differential training exhibited greater jump distances than repetition-based training ($p<0.05$) but no training effect was found between pre- and post- assessments for either training approach ($p>0.05$). Similarly, vertical GRFs were significantly different between the groups ($p<0.05$) and no training effect was found ($p>0.05$). Horizontal take-off velocity showed a significant increase with greater velocities achieved post-training ($p<0.05$). Individual differences displayed low or near zero correlations with performance variables, but horizontal velocity displayed a high correlation with jump distance ($r\ (27) = 0.69$). Overall, differential training failed to show the expected performance enhancement for this discrete, explosive motor task when compared to repetition-based training. The lack of correlation effects shows that training is uninhibited by individual differences which may describe a more universal benefit for implementation across

populations. Further research is needed to better understand the task factors where movement variations associated with differential training influence skill acquisition.

INTRODUCTION

In both simple motor tasks and sport skills, individuals never truly repeat the same movement pattern. Yet, the repeatability of optimal movement patterns is typically considered an attribute of being highly skilled. Given the abundant evidence of movement variability occurring between repeated task repetitions (Bauer & Schöllhorn, 1997; Bernstein, 1967), a critical question arises as to whether practice designs should induce movement variability in order to promote skill acquisition and efficient performance outcomes (Ranganathan & Newell, 2013). A variety of practice design have been used to promote skill acquisition and retention; however, the primary focus has been on variability at the task outcome level and within the framework that movement errors need to be constantly corrected throughout practice. In contrast to the idea that movement errors are undesirable, the differential learning theory (Schollhorn et al., 2006) posits that incorporating variability allows the opportunity for movement exploration that facilitates the self-organization of an optimal motor pattern in a manner that distinctly differs from traditional learning perspectives.

Movement variability in training, introduced through various approaches, has the potential to allow individuals the opportunity to explore movement errors which can lead to adjustments around an optimal motor pattern or deviance from unwanted movements all together. Noise is broadly defined as “the random fluctuating variability of background signals that can interfere with transmission and reception of a signal containing information” (Schollhorn et al., 2006). Practice environments that promote the need for different movement solutions stimulate individuals’ creative process more than repetition-based models of learning.

This freedom in movement exploration develops a broader range of skills configurations that an athlete can use during performance and leads to motor task specialization in later stages of training (Santos et al., 2016).

The theoretical basis for differential learning centers around principles of self-organization associated with dynamic systems theory and concept of stochastic resonance (Schollhorn et al., 2006). In practice, a lack of movement repetition induced by requiring an individual to execute a range of motion patterns allows for the probability of an individual to find a movement solution that fits specific constraints related to the learner and the motor tasks. Accordingly, increasing the breadth of movement fluctuations experienced with various motor executions can transition an individual towards more stable, optimal movement solutions while increasing movement adaptability when confronted with external perturbations (Schollhorn et al., 2006). Another key element of differential learning that contrasts traditional perspectives is highlighted by a low emphasis of direct external feedback. Specifically, differential learning proposes that correcting movement patterns after every repetition prevents the system from utilizing unique fluctuations needed to fully facilitate the self-organizing processes that are integral for skill acquisition (Savelsbergh et al., 2010). Furthermore, individual differences within movement solutions are accepted and there is less reliance on the use of direct external feedback that guides individuals toward a prescribed ideal movement pattern.

Specifically for dynamic sports tasks, the need for creativity and originality becomes vital when an athlete must quickly choose a motor skill to accomplish a preferred outcome and external feedback has a potential interfering effect on these properties (Santos et al., 2018).

Behavior modification emerges as a consequence of individuals making conscious adjustments when there is no coaching to correct their movement. As a result, differential learning stimulates the creation of many skill configurations that emerge through its varied repetition design.

High variability in outcome is often undesired in performance and credited to inconsistent movement execution. It becomes the aim of many coaches and practitioners to eliminate movement variability because it was assumed to be detrimental to skill. Traditional methods have therefore utilized high repetition designs to eliminate perturbations in the system in an attempt to achieve the desired optimal movement pattern. Conversely, differential learning approaches promote an increase in motor noise to stimulate the system toward adaptability (Santos et al., 2018). Variability is not seen as noise to be eliminated, but rather an opportunity for participants to adapt and explore the most efficient movement for their system. Contextual interference is inherent with application of differential practice designs, and has been shown to accelerate motor learning compared to traditional designs through its incorporation of practice variability and different tasks (Hall et al., 1994). Contextual interference designs has shown to yield lower results than blocked designs during practice, but greater rates of retention and transfer skills at a later date (Fialho et al., 2006).

The extent of differential training has been applied to a variety of sports tasks to increase performance. Increasing the presence of movement fluctuations in resistance training has shown benefits for change of direction, speed, and maneuverability when applied in youth basketball players (Schollhorn 2019). Incorporating different postural positions for novice skaters has revealed a significant increase in skating start performance (Savelsbergh et al., 2010). For experienced athletes, random practice schedules have been shown to increase the retention of volleyball serves (Fialho et al., 2006) and promote positive transfer of skills for baseball players

(Hall et al., 1994). Differential learning promotes originality and versatility in soccer players while also establishing positioning regularity through variance (Santos et al., 2018). Hockey players who train with an increased range of stochastic perturbations adopted a better hockey flick technique to novel situations (Beckmann et al., 2010). Introduction of technique variances with no corrective feedback improved passing, dribbling, and feet juggling for soccer players (Bozkurt, 2018). Retention and learning skills are increased for shot put, an explosive closed motor task (Beckmann et al., 2016). Overall, despite the evidence of enhanced skill acquisition in various tactical environments, there still remains a gap in understanding the application of differential learning to a variety of motor tasks.

As highlighted above, the overall effectiveness of differential learning has been shown to produce positive training effects for motor skills performed in dynamic settings and that require constant adaptability, such as in soccer, hockey, and baseball. However, aside from the original investigation using the shot-put task, limited investigation has occurred for discrete motor skills that require maximal force production. The aim of the current study, therefore, was to evaluate whether the application of differential learning to the standing broad jump task enhanced skill acquisition as compared to a traditional, repetition-based approach. According to previous literature, it was predicted that differential learning would positively enhance task outcome (jump distance) as well as force production characteristics of novice jumpers as compared to a repetition-based approach.

METHODS

1.1 *Participant Data*

A total of 38 heathy, physically active individuals (24 female, 14 male, height: M=170.9 cm, SD=10.6 cm; weight: M=69.2 kg, SD=12.3 kg) between the ages of 18 and 30 (M=22.56, SD=1.41 years) were recruited from a university population to participate in this study. Participants were excluded if they had previous formal training in the long jump or broad jump task or an injury to the lower extremity within the past year. Individuals were randomly assigned into either a repetition-based (control) or a differential (experimental) training group and all participants that completed the study requirements were provided compensation. A total of nine participants were excluded from the analysis due to failure of completing both pre- and post-training assessments, failing to complete the required accountability training logs, or technical issues during data collection. The experimental procedures were approved by the institutional review board for human research. All individuals provided written informed consent prior to completing study procedures and received monetary compensation for completing all study phases.

1.2 *Instrumentation*

Jump distances were measured from the starting line marked on the force plate to the back of the nearest heel at the jump landing and recorded using a metric tape measure. A force plate (OR6-7, AMTI, Boston) was used to record ground reaction forces (GRF) in the anteroposterior (GRF_{ap}), and vertical ($GRF_{vertical}$) directions. Force data were sampled at 150 Hz.

1.3 *Standing Broad Jump Testing Procedures*

Following consenting procedures, the participant completed an active warm-up that included one set of eight repetitions of each of the following exercises: bodyweight squats, alternating high kicks, alternating forward lunges, butt kicks, and alternating lateral lunges. Next, the participant performed four maximal-effort broad jumps for distance from the force plate and were provided a rest period of 30 seconds between each attempt. Post-testing sessions occurred eight days after pre-testing whereby participants were taken through the same active warm-up and completed another set of four maximal-effort broad jumps.

1.4 *Training Sessions*

A total of four training sessions were completed between the pre- and post-test assessments. Training sessions for the repetition-based group consisted of an active warm up (described above) followed by 20 repetitions of the standing broad jump task with up to 30 seconds of rest in between repetitions. The differential learning training sessions consisted of the same active warm up and 20 single-repetition variations of the standing broad jump task (see Table 1). The first training session was conducted immediately following pre-testing to promote movement familiarity. The remaining three training sessions followed the same format and were completed by the participant's outside of the laboratory (Figure 1). Participants were required to log (paper and video) the at-home training sessions and the researchers verified the logs at post-testing.

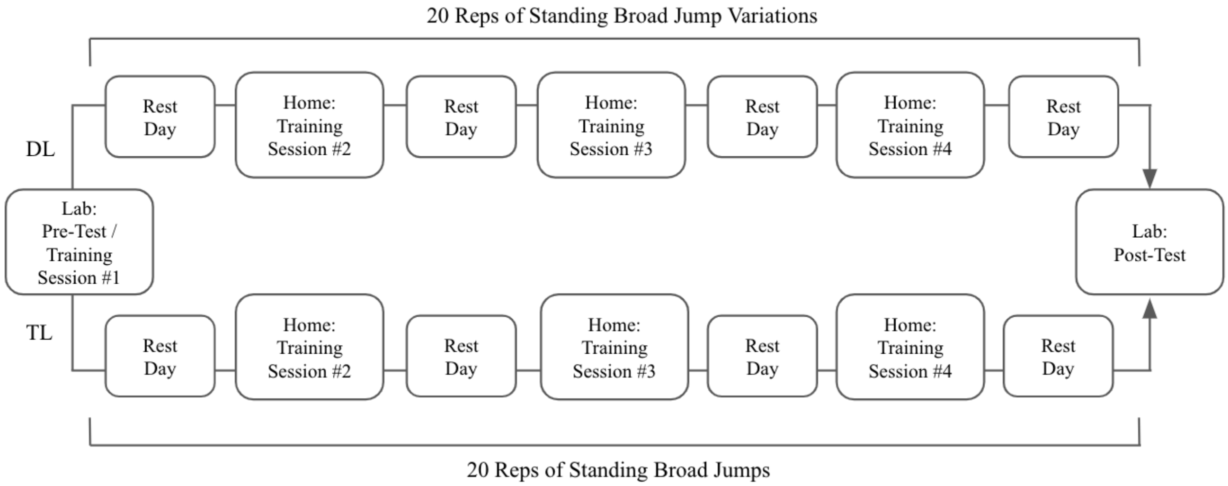

Figure 1: Study design diagram illustrating the training timeline for differential (top) and repetition-based (bottom) groups with pre- and pos-test assessments.

Table 1: Broad jump variations for Differential Training.

Repetition	**VARIATION**
1	Starting with feet together.
2	Starting with feet wider than shoulder width.
3	Jump with no arm swinging.
4	Jump utilizing a big circle arm swing.
5	Jump swinging only the left arm and keeping the right arm still by holding the waist.
6	Jump swinging only the right arm and keeping the left arm still by holding the waist.
7	Starting at a deep squat depth.
8	Starting at a shallow squat depth.
9	Beginning facing left, rotating in the air to land facing forward.
10	Beginning facing right, rotating in the air to land facing forward.
11	Jump at a 45-degree angle, beginning and ending facing forward. Participants will jump in the left direction.
12	Jump at a 45-degree angle, beginning and ending facing forward. Participants will jump in the right direction.
13	Jump from the left leg, landing with both feet.
14	Jump from the right leg, landing on both feet.
15	With feet staggered; left foot will be in front of right foot.
16	With feet staggered; right foot will be in front of left foot.
17	Starting backwards and jumping clockwise 180 degrees, landing facing forwards.
18	Starting backwards and jumping counterclockwise 180 degrees, landing facing forwards.
19	Consecutively perform a small vertical jump and then a broad jump.
20	Start facing backwards with feet perpendicular to the starting line and jump in the backwards direction.

1.5 *Data Analysis*

Kinetic data from the force plate were imported into Visual 3D (C-Motion, Germantown, MD) and filtered using a four-order Butterworth filter with a 10 Hz cut-off frequency. Custom-written pipelines were constructed to identify movement initiation, peak vertical force, and toe off events. Movement initiation was determined by ±3 SDs from a steady baseline state collected prior to movement initiation. All movement events were checked and visually confirmed prior to computing the following variables. Peak ground reaction forces (GRF_{peak}) in the vertical direction were identified and normalized to bodyweight. Rate of force development (RFD) was computed as the change in force (GRF_{peak} minus $GRF_{minimum}$) divided by the temporal window of these two force events. Lastly, the normalized horizontal impulse was determined from GRF_{ap} between the events of movement initiation and toe off, and used to calculate horizontal velocity (V_{hor}) at take-off.

1.6 *Statistical Analysis*

The maximum jump distance from the four pre- and four post-test assessment was used to determine each participant's broad jump performance. Each dependent variable was analyzed in a repeated measures ANOVA with a within-subject factor of test phase (pre/post) and a between-subject factor of training group. Partial eta-squared (n_p^2) was reported to measure effect size and interpreted as small (>0.01), moderate (>0.06), or large (>0.14). All statistical analyses were run in SPSS (IBM) with a level of significance defined as $p<0.05$.

RESULTS

The best jump distance out of the four attempts pre- and post-assessment was used to index performance. The results revealed a statistically significant main effect of group for jump distance, F(1, 200) = 34.04, p<0.001, η_p^2==0.15 with differential learning (M=1.91, SE=0.3 m) exhibiting larger jump distances than the repetition-based group (M=1.65, SE=0.03 m). The main effect of test did not reach statistical significance but trended towards greater jump distances during the post-test, F(1, 200) = 2.10, p=0.15, η_p^2==0.01. No significant differences were found for any of the interaction effects.

The normalized GRF_{peak} revealed a significant group main effect, F(1,192) = 10.22, p<0.01, n_p^2=0.05, with the differential group (M=2.25, SE=0.03 BW) showing greater peak forces than the repetition-based group (M=2.13, SE=0.03 BW). No other main effects or interactions were found.

The results of the RFD revealed a lack of significance for the main effects of group and test. However, the group x test interaction, F(1, 192)=2.42, p=0.12, η_p^2=0.012, trended toward a decrease in the rate of force development for the differential group (PRE: M=3174.91, SE=226.60 Ns^{-1}; POST: M=2547.15 , SE=226.60 Ns^{-1}) and a modest increase for the repetition-based group (PRE: M=2770.01, SE=244.76 Ns^{-1}; POST: M=2875.90, SE=244.76 Ns^{-1}).

A significant group main effect was found for the vertical impulse, F(1, 214)=5.05, p<0.05, η_p^2=0.23, with the differential group (M=874.70, SE=18.70 Ns) showing larger values than the repetition-based group (M=813.92, SE=19.54 Ns). No other main effects or interactions were found.

A signification main effects of group $F(1, 226)=36.06$, $p<0.001$, $\eta_p^2=0.14$ and test $F(1,226)=4.45$, $p<0.05$, $\eta_p^2=0.02$ were found for horizontal velocity. The horizontal velocity was greater in the post-test (M=2.46, SE=0.03 m/s) than the pre-test (M=2.38, SE=0.03 m/s), while differential (M=2.54, SE=0.03 m/s) had overall greater takeoff velocities compared to the repetition-based group (M=2.29, SE=0.03 m/s).

A change score (post minus pre) for each performance variable and individual pre-survey data was computed. Correlation coefficients of the change scores were computed to determine the best predictor variables for training effect. Correlation coefficients were found to be near zero for perceived skill level/jump distance and perceived skill level/horizontal velocity. Low correlations were found for perceived skill level/rate of force development, r (27) = 0.11, exercise frequency/jump distance r (27) = 0.23, exercise frequency/rate of force development r(27) = 0.06, exercise frequency/horizontal velocity r (27) = 0.10, jump distance/rate of force development r (27) = -0.08, and rate of force development/horizontal velocity r (27) = -0.06. A high correlation was found for jump distance/ horizontal velocity r (27) = 0.69.

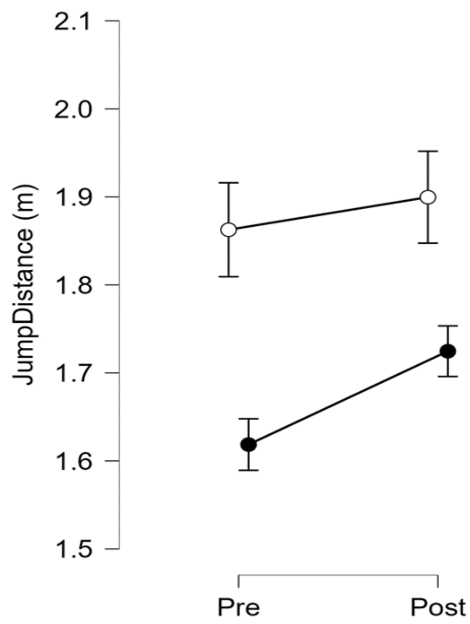

Figure 2: (DL – black circle; RBL – white circle) Jump distance performance during pre- and post-training assessments for differential and repetition-based groups. A significant main effect of group and both groups trended toward larger jump values during post-testing.

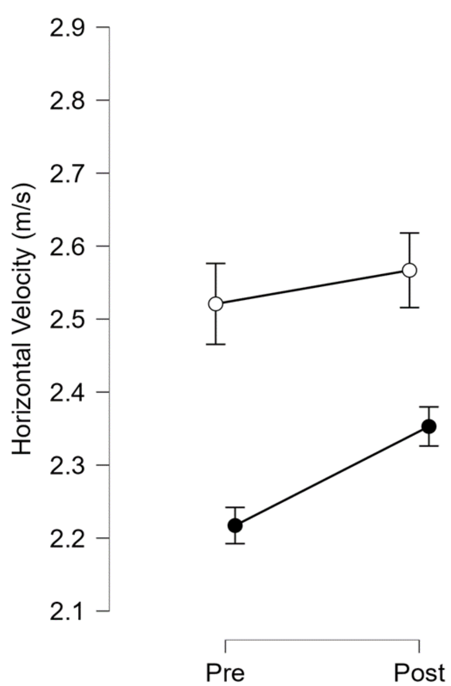

Figure 3: (DL – black circle; RBL white circle) Horizontal velocities were greater for both groups in post testing.

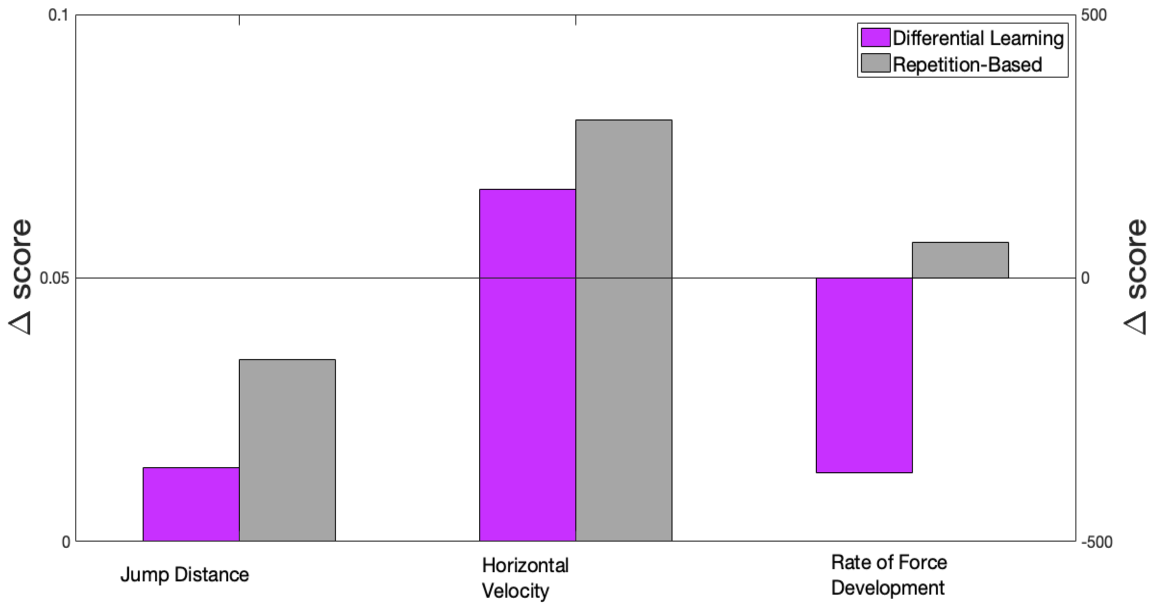

Figure 4: Repetition-based learning showed a greater increase in all variables while differential learning also showed negative improvement in rate of force development.

DISCUSSION

The aim of the current study was to compare the effect of differential learning to a repetition-based approach on the acquisition of a standing broad jump task among novice individuals (i.e., lacking formal jumping experience). In accordance with differential learning theory, it was predicted that movement variations (i.e., changes in jump direction, body rotation, arm utilization, and starting foot position) would facilitate the self-organization process of efficient movement patterns in the acquisition of the broad jump task. However, the results did not support our original prediction in that the practice effect of differential training was similar to that of repetition-based training and failed to show the expected performance enhancement following exposure to training environments that varied the movement executions.

The duration of training included four training sessions distributed over a total of eight days and the results revealed a trend toward statistical significance for jump distance in both training groups. Horizontal velocity at take-off did show a significant training effect providing an indication of an effective training volume. The lack of a training effect for the performance outcome measure (jump distance) may be due to the limited exposure to the explosive movement patterns required to execute the standing broad jump. A wide range of training durations have been implemented in previous investigations of differential. Short-term training studies includes investigations with a single session examining postural changes (James, 2014), five days for learning volleyball serves (Fialho et al., 2006) and one week for recreational speed skaters improving start times (Savelsbergh et al., 2010). Longer training durations demonstrating the positive effects of differential learning have spanned a range between four weeks to five months of training while examining a variety of motor tasks, such as shot put, hockey passes, baseball hitting, tactical behavior in soccer (Beckmann et al., 2016; Hall et al., 1994; Henz & Schöllhorn, 2016; Santos et al., 2018). The training volume used in the current study may be an indication that additional practice is required for this explosive movement and for novice learners to promote the proposed benefits of differential learning. As suggested by Tassignon and colleagues (Tassignon et al., 2021) in a recent meta-analysis, it will be important for future investigations to carefully consider how factors related to training volume, motor task, and learner population influence the overall effects of differential training.

A finding in support of the idea that individuals may need further exposure to the explosive components of the standing broad jump can be seen in the rate of force development (RFD) results (figure 4). In contrast with our original hypothesis, repetition-based training trended toward a significant increase in RFD during post-testing while differential training displayed a decreasing trend from pre- to post-testing. Individuals in the differential learning environment may have experienced difficulty with the maximal force production elements when performing the jump variations. This aspect may have further compounded any training benefit when considering the limited exposure of each jump variation throughout the study. In contrast, repetition-based training exposed individuals to the same movement pattern that appears to have allowed for greater increases in force production during each repetition. Furthermore, differential training had the additional challenge of completing a new jump variation after every repetition and individuals may have focused on developing a non-optimal movement solution to meet the task execution goal rather than producing maximal effort in order to achieve the greatest jump distance. Importantly, while training consisted of no movement correction during the acquisition process to promote the self-organizing feature of differential learning, supervised training sessions can provide further encouragement and should be considered in future investigations.

According to Schollhorn, it is ideal for DL movement variations to cover a maximal range of motion patterns in order to optimally promotes self-organization and to become in resonance with individual needs (Schollhorn et al., 2006). However, no study to date has fully explored the degree or ideal bandwidth of movement variability that exists for different movement tasks. The lack of a training effect displayed for the current differential training group may have been influenced by the large range of movement variability experienced during training. It may be the case that the standing broad jump variations were too dissimilar to a standard broad jump task. Based on the variations used by Beckmann (2016), the current study used variations that included elements related to jump direction, initial foot position, flight rotation, and arm swing patterns. Both tasks (shot-put throw and standing broad jump) represent explosive closed-chain movements with the main difference being propelling an object versus projecting the body.

However, the planes of motion associated with each also slightly differ in that the broad jump occurs predominantly in the sagittal plane; whereas, the rotational elements of the shot-put throw potentially add more movement variations. Overall, future investigations are needed to better identify the appropriate bandwidth of movement variability and it may be necessary to develop a common model task paradigm around differential learning in order to evaluate the robustness of this theoretical approach.

A few limitations of the current study need to be considered. First, the novice population used was based on a lack of formal jump training that typically accompanies participation in sports such as basketball, triple jump, and high jump; however, the wide range of physical activity reported may have impacted the findings. Next, together with the diverse degrees of skill level perception, it may be the case that some individuals incorporate plyometric activities in their normal training resulting in different degrees of improvement. Lastly, while written and video logs were collected to ensure accountability, the effort level during training could not be strictly controlled. As highlighted above, supervised training session may be more appropriate for this explosive motor tasks rather than allowing individual's degree of motivation play a factor into the results. However, a hypothesized limitation regarding the impact of individual differences proved to not have an effect on training. Prior exercise frequency levels and perceived skill levels showed little to no correlations with performance variables indicating that differential training can be more broadly applied to many populations.

In conclusion, the effects of differential learning may differ concerning tactical and creative movements. The variations used for the explosive broad jump movement must specifically contribute to maximal force production in order to develop self-organizing processes for the desired movement rather than the variations. Further studies should aim to investigate the appropriate bandwidth of variations for explosive motor tasks and extend the duration of the training period to optimize opportunity for a transfer affect to develop from training to post-testing.

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