



Nonlinear assessment of motor variability during practice and competition for individuals with different motivational orientations



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ABSTRACT

The aim of the present study was to document how differing motivational orientation profiles, situated within environmental constraints (i.e., a competitive and practice environments) influence the nonlinear variability of performance and subsequent retention of a visual motor tracking skill. Myriad research associates atypical nonlinear aspects of motor variability with pathology; however, few empirical efforts have explored the influence of individual differences and environmental factors on nonlinear aspects of motor output and skill retention. Participants performed an isometric force-tracking task, matching the force indicated by a target line displayed across a computer screen. Dependent variables were performance outcome (root mean squared error) and the complexity of the produced signal (Sample Entropy) across practice, competition, and retention. Participants with high task orientation, regardless of high or low levels of ego orientation, exhibited the greatest visual motor tracking improvement as well as the greatest increases in irregularity of force variability from practice to competition and retention. We conclude that individual differences play a key role in the structure of continuous behavior, and that this structure influences the learning of continuous motor skills.

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1. Introduction

Human movement inherently involves variability (Bernstein, 1967). Variability is most clearly seen in the multiple executions of discrete motor acts (e.g., placement of basketball free throws). No two movements are ever executed in precisely the same way, leading to what has classically been viewed as error in the planning and or execution of movement (Schmidt & Lee, 2011; Summers & Anson, 2009). The traditional goal of motor learning is thus to decrease errors in performance outcomes (e.g., distance from the target) over practice. Variability, however, can also be seen in the performance of continuous tasks such as driving a car or tracking the motion of an object on a computer screen (Poulton, 1974). This “process” variability manifests as variations of continuous performance over time, such as deviations of the center of pressure during postu-

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ral sway or fluctuations of isometric visual motor tracking trajectory (Cavanaugh, Guskiewicz, & Stergiou, 2005; Newell, Studenka, & Hu, 2014). When examined over time, variability does not necessarily indicate error that must be overcome through practice; rather, greater variability is often seen in adaptive behavior of more healthy individuals. For example, younger individuals showed greater postural sway during quiet stance when compared to older individuals (van Emmerik & van Wegen, 2002a).

For continuous tasks, quantifying the overall amount of variability (e.g., amount of postural sway) does not always tell the whole story. Instead, nonlinear measures of *how* variability changes over time can enhance understanding of how behavior is controlled and why differences might exist among groups of individuals (Goldberger, 1996; Goldberger, Peng, & Lipsitz, 2002; Korobeinikov & Maini, 2005; Stergiou & Decker, 2011a). Fluctuations in continuous behavior are thought to emerge from concurrent processes, including cognitive, physiological, and sensory motor interactions (e.g., feedback; Gilden, 2001; Gilden et al., 1995). The structure of fluctuations in continuous motor output is neither completely random (white noise) nor completely predictable (e.g., sinusoidal motion), leading to the characterization of human behavior as complex. Complexity is often used synonymously with adaptability and serves to indicate a system's ability to adapt to new and changing circumstances and to resist external perturbations. For example, it is well established that, as the human system ages, behavior becomes less complex, purportedly due to the loss of faster time scales in physiological and cognitive processes (Lipsitz, 2002; Lipsitz & Goldberger, 1992; Vaillancourt & Newell, 2002).

Entropy – a common measure of variability structure – quantifies the regularity of a time series (e.g., postural sway position over time) and has been used as a measure of signal complexity. Decreased complexity (i.e., greater regularity) of fluctuations is often equated to loss of stability or adaptability. For example, more regularity in mean heart rate over time has been linked to heart pathology (van Emmerik & van Wegen, 2002), and more regularity in postural sway variability has been documented in athletes following concussion (Cavanaugh et al., 2006, 2005; Sosnoff et al., 2011), despite nearly equal performance outcomes.

In light of the emerging use of nonlinear measures for the assessment and diagnosis of human pathology (Goldberger, 1996; Goldberger et al., 2002; Stergiou & Decker, 2011; Stergiou et al., 2006; Vaillancourt & Newell, 2002), understanding the potential influences of environmental (i.e., the nature of one's surroundings) and cognitive (i.e., one's internal state of thought) factors on nonlinear aspects of human performance is critical. To date, however, little research has been designed to specifically investigate the influence of both individual and environmental differences on nonlinear aspects of human behavior (e.g., Donker, Roerdink, Greven, & Beek, 2007).

Extant research indicates that a reduction in the complexity of motor performance may be related to reduced automaticity or more conscious control (Wulf, McNevin, Fuchs, Ritter, & Toole, 2000; Wulf, McNevin, & Shea, 2001; Wulf, Töllner, & Shea, 2007). Greater mean frequency in the time series of the platform displacement was seen when participants focused externally on a visual target rather than internally on their own movements (Wulf et al., 2001). This greater mean frequency typically indicates the incorporation of faster fluctuations and, therefore, greater complexity. Greater mean frequency was also accompanied by better overall performance as measured by the average deviation of the platform from parallel (root mean squared error; RMSE). The incorporation of higher frequencies into postural adjustments in a continuous balance task was attributed to lesser cognitive control and greater automaticity evoked by focus on an object external to the body.

In addition to cognitive and attentional influences, the environment in which actions are performed may influence nonlinear aspects of behavior. Notably, zebra finches (a type of songbird) exhibit reduced variability in the mean frequency of song production in a performance (i.e., singing in the presence of a potential mate) versus a practice (i.e., singing alone or in the absence of a potential mate) environment (Kao, Doupe, & Brainard, 2005). Interestingly, when the area most similar to the human basal ganglia was lesioned in these birds, variability in the mean frequency of song production was reduced, indicating that variability present during practice served a function for learning. It is unclear whether or not these findings pertain directly to human motor performance; however, the influence of environmental constraints on nonlinear aspects of motor performance (e.g., practice vs. performance/competition) warrants further exploration.

Research in education and sport settings suggests that within-individual differences may attenuate the effect of environment on linear aspects of performance such that some people are influenced differently by competitive situations than others. This hypothesis builds from field theory (Lewin, 1935), which viewed human behavior as an interaction between a person and her or his environment. Contemporary research highlights the importance of an individual's motivational orientation in determining behavior. Achievement goal theory (Nicholls, 1984; Nicholls, Cheung, Lauer, & Patashnick, 1989) is built from seminal research on identity goals that lead to helpless or mastery responses in a range of achievement contexts (Dweck & Elliott, 1983; Dweck & Leggett, 1988). The contemporary version of achievement goal theory outlines three primary factors that influence an individual's motivation: goals, perceived ability, and behaviors (see Elliot, 2005; for a comprehensive review). The combination of these three factors yields two orthogonal motivational orientations that individuals subsequently use to define success and ability: *task* orientation and *ego* orientation (Duda, 1989; Duda & Nicholls, 1992; Newton & Duda, 1993a). Individuals with high task orientation demonstrate high intrinsic interest and define competence based on learning, hard work, task completion, and personal improvement (Duda & Ntoumanis, 2003a; Nicholls, 1989). These individuals typically choose learning opportunities at the risk of displaying mistakes and continue to problem-solve when encountering failure. Conversely, individuals with high ego orientation demonstrate differentiation of effort and ability, and define competence as outperforming others or performing equally well with less effort (Ames, 1984; Duda et al., 1995; Newton & Duda, 1993). These individuals typically avoid learning opportunities that have risk of displaying error and employ fewer problem-solving strategies when facing failure.

Decades of research in sport and exercise psychology have focused on athletes' motivational orientations as they relate to perceptions of ability and performance outcomes (see Harwood, Spray, & Keegan, 2008, for a review). Moreover, research has been designed to examine the impact of achievement goals on motor performance outcomes (e.g., Cury, Elliot, Sarrazin, Da Fonseca, & Rufo, 2002), as well as motor performance in varied social situations (e.g., Elliot, Gable, & Mapes, 2006). Despite these efforts, there remains scant evidence of how an individual's motivational orientation may affect the variability of continuous motor performance prior to, during, and after competition, and furthermore, how differences in the structure of variability may influence the retention of continuous motor skills. The aim of the present study was to address this gap by documenting how differing motivational orientations, situated within environmental constraints (i.e., a competitive versus a practice environment) influence the nonlinear variability of performance and subsequent retention of a visual motor tracking skill. Furthermore, we were interested in how changes in the structure of variability during practice and competition translated to overall retention of a continuous visual motor tracking skill.

Because increased variability during the practice of discrete tasks typically leads to poorer acute performance but better overall retention (Schmidt, 1975; Shea & Kohl, 1990; Van Rossum, 1990; Wrisberg & Liu, 1991), we hypothesized that greater irregularity (greater SampEn) during practice (Day 1) and competition (Day 2) would lead to better retention (Day 3), reflecting greater overall learning (smaller RMSE) of the visual motor tracking task. Furthermore, based on past literature (e.g., Duda & Ntoumanis, 2003; Nicholls, 1984), we hypothesized that individuals in the high-task, low-ego orientation profile would exhibit the greatest retention of visual-motor tracking, whereas individuals in the low-task, high-ego orientation would exhibit the least retention of visual-motor tracking.

2. Materials and methods

2.1. Participants

A total of 55 participants ($n = 28$ female; $n = 27$ male) were recruited from the population of undergraduate students at a large university in the Rocky Mountains. Forty-two participants completed all three days of testing. One of the participants was left handed, and was therefore removed from the final analysis, resulting in a final N of 41 participants ($n = 22$ female; $n = 19$ male; $M_{\text{age}} = 22$ years; $SD_{\text{age}} = 3.5$ years). Informed consent procedures were approved by an Institutional Review Board for the protection of human subjects.

2.2. Apparatus, procedure and design

Upon entering the lab, tasks were explained to participants and informed consent was obtained. Participants completed three sessions, each on a different day, with a maximum of two days between sessions. On Day 1, the participant completed the Task and Ego Orientation in Sport Questionnaire (TEOSQ) measuring motivation orientation (Chi & Duda, 1995). In past work, the TEOSQ has demonstrated internal consistency of scores (i.e., Chronbach's α) ranging from 0.77 to 0.87 for the task-related items and 0.77–.91 for the ego-related items. In the present study, internal consistency of scores was 0.80 for task-related items and 0.84 for ego-related items, suggesting good reliability across goal orientation items. Additional demographic information (i.e., age, gender, video game experience) was obtained through a brief verbal interview. No correlation was found between years of video game experience and any of our outcome difference scores. The non-significant correlations ranged from -0.08 to 0.19 . The participant was seated at a table (70 cm high) facing a computer monitor with the eyes approximately 61 cm from the base of the screen. The participant's body was aligned with the center of the screen with both feet placed flat on the floor. The distal knuckle of the index finger of the dominant hand was placed against a load cell (ATI, nano17 force sensor/transducer; see Fig. 1). When the participant pressed on the load cell, a cursor on the computer screen moved upward, leaving a traced path while moving across the screen horizontally at a constant rate. The participant was given a 40-s acclimation trial in order to get a feel for pressing on the load cell. Instruction was given to avoid using multiple fingers for the task or lifting the palm. Then, three trials – each of 5-s duration – were given which captured a participant's maximal voluntary contraction (MVC). Following this, a practice trial was given during which a participant practiced pressing with the appropriate amount of force. A participant practiced aligning the force trace (a white line that represented the amount of force used by the finger) with a red line that spanned the length of the computer screen (see Fig. 2). For this practice trial – and for subsequent experimental trials – the red line on the screen was centered at 10% of the participant's MVC, and the screen spanned from 5 to 15% of the participant's MVC. On Day 1, 25 trials of attempting to maintain a constant force were performed. Each trial was 20 s long. After each trial, a root mean square error (RMSE) score was displayed on the screen. The RMSE score captured the average deviation from the red line in pixels. Participants were instructed to practice improving their performance (by lowering the RMSE score) in preparation for competition on Day 2. Participants were monitored during the trials to maintain form and level of effort.

On Day 2, the participant entered the lab and sat across from a confederate who was also sitting in front of a monitor with the same parameters as the participant (see Fig. 3). The participant was told that this confederate was another participant and that he/she would be competing against them. The participant sat at the same computer as he/she had for Day 1 and the confederate faced the participant at his/her own monitor. The monitors were not visible in any way to the other competitor. The participant and confederate were instructed to try to win as many of the 21 trials as possible. The initial process was the same as Day 1 (an acclimation trial, three trials to capture maximal force, and a practice trial before competition). During

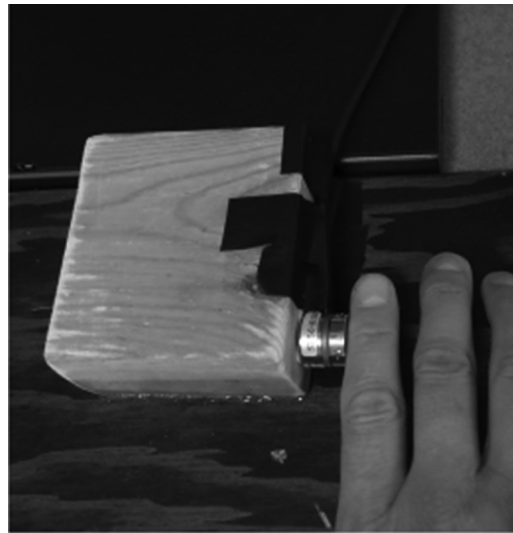


Fig. 1. A top-down view of the finger placed on the load cell.



Fig. 2. Picture of a lab member demonstrating the practice task.

the trials, the confederate pretended to press on his/her own load cell across from the participant. The data from the 21 trials against which the participant was competing were the 21 best trials collected from that same participant's Day 1 performance, presented in a randomized order. At the end of each trial, the RMSE score of the participant was shown. In addition, the RMSE score of the confederate (a trial from Day 1) was shown on the participant's screen, and the confederate's performance was shown to the participant as a blue line across the screen. If the participant exhibited a lower RMSE score than the confederate on the trial (less deviation from the centered red line), "YOU WON" was displayed on the screen in green font (see Fig. 3). If the participant had a higher RMSE score than the confederate on the trial, "YOU LOST" was displayed on the screen in red font. In addition, the win/loss record was displayed at the end of the trial in the top right of the screen. After the completion of 21 trials, the overall win/loss record was presented and an overall win or loss was presented on the screen as either "YOU WON, CONGRATULATIONS" in green or "YOU LOST, BETTER LUCK NEXT TIME" in red. Upon completion of Day 2, both participant and confederate were thanked and Day 3 was scheduled with each. Table 1 displays the number

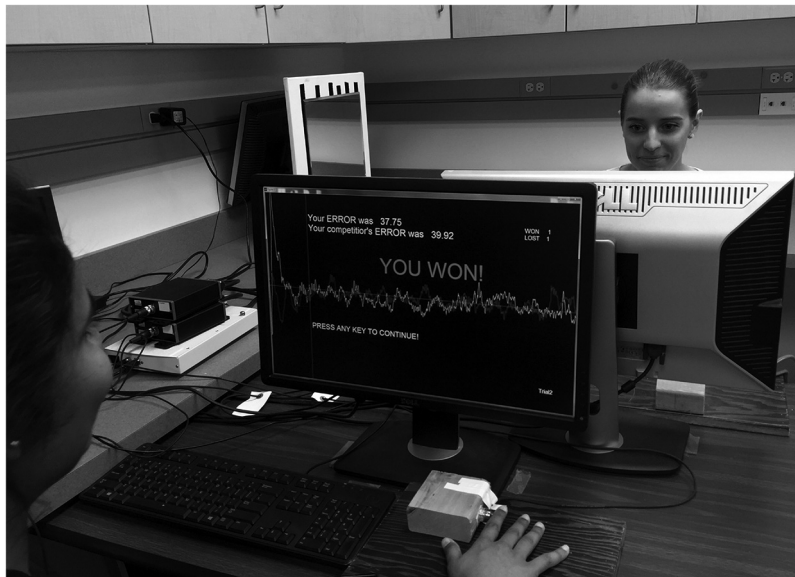


Fig. 3. A picture of two lab members simulating the competition task.

Table 1

Number of participants and win loss record for each group.

	Low Task	High Task
High Ego	$n = 11$ win: 11, loss: 0	$n = 13$ win: 11, loss: 2
Low Ego	$n = 8$ win: 7, loss: 1	$n = 9$ win: 8, loss: 1

of participants in each group as well as the overall win loss record for the group. Most participants were able to beat their day one scores.

On Day 3, a participant followed the same initial procedure as Days 1 and 2 without a competitor (acclimation, MVC, practice). Because we were only interested in measuring retention on Day 3, we collected five trials of the task. An average of more than five trials would reflect both adaptation (within a session) as well as retention (performance improvement carried over from a previous day). The participant was instructed to try to produce as low an RMSE as possible. The RMSE score was presented on the screen following each trial. The participant was thanked and informed about the purpose of the study, that the competition was, in fact, against her or his own best trials from Day 1, and that the other participant was actually a confederate from the lab.

2.3. Data collection and analysis

Using the TEOSQ, each participant was given a score for task and ego orientation. Because we were interested in comparing those with different motivational profiles, the mean of each orientation was used to divide the participants into groups of high/low tendencies. This profile classification strategy has been used in past work in educational and sport settings (see Dunn & Dunn, 1999; Fox et al., 1994). As these orientations exist on orthogonal continua, four subgroups resulted for analysis: high task/high ego, high task/low ego, low task/high ego, and low task/low ego (Fig. 4).

Visual motor tracking data were collected at 100 Hz, and analyzed via custom written software in MATLAB. Trials were 20 s in length. The first 3 and last 2 s of the trial were removed, and 15 s were analyzed (1500 samples). Trials where force was not consistent (e.g., where it appeared that a participant's finger slipped off of the force sensor), or when force was so low or high as to be off of the screen (under 5% or over 15% of a participant's MVC) were removed from analysis. A total of six trials were removed, all from Day 1.

The present design considered both static and dynamic measures of performance. Static performance was assessed using the RMSE value of each trial, which represented the average deviation of the participant-produced line from the goal line. Dynamic performance was assessed using the nonlinear measure of Sample entropy (SampEn). SampEn is used to quantify the frequency and similarity of neighboring data points in a time series, where more frequent and more similar instances of close neighboring data points lead to lower values of entropy and indicate more regularity or predictability in the time series (see Richman & Moorman, 2000). For the present data, we used the standard template length of 2 and a matching threshold of 0.2. In other words, we looked at data points right next to each other to determine how similar they were, and

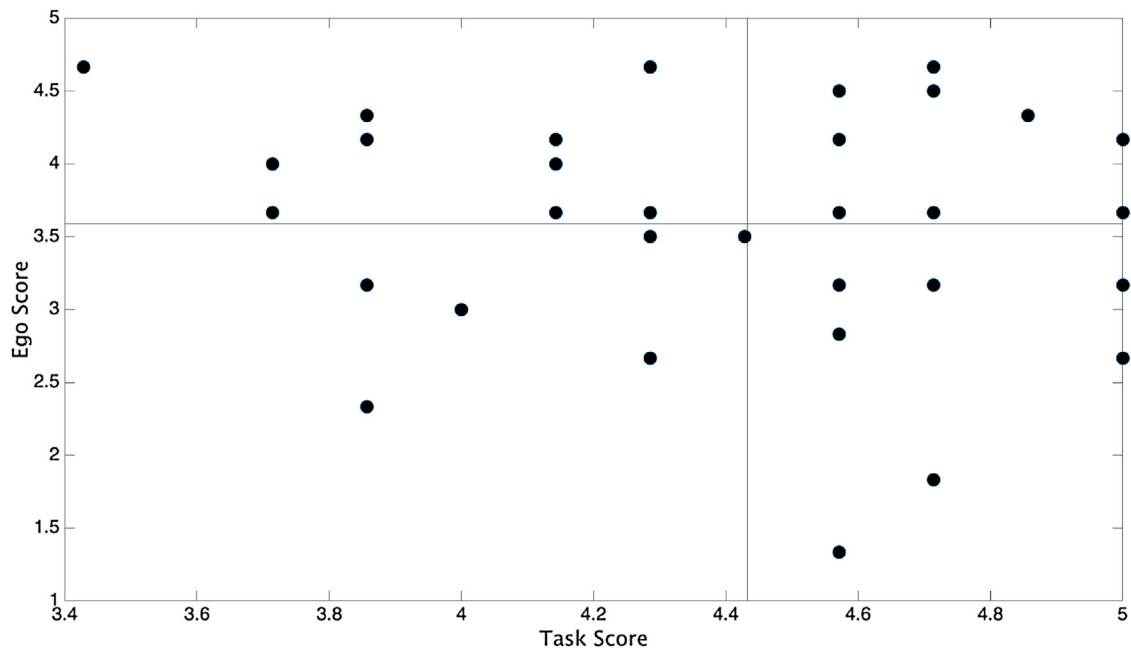


Fig. 4. Distribution of task and ego scores for all participants. Mean values (horizontal and vertical lines) for both task and ego were used to delineate groups into high and low categories.

used a threshold of 0.2 times the standard deviation of the time series to determine whether or not neighboring points were similar or not. SampEn essentially gives a ratio of similar time points over total time points and, therefore, quantifies the amount of regularity in a time-series (Lake, Richman, Griffin, & Moorman, 2002; Richman & Moorman, 2000). Smaller values of approximate entropy indicate more regularity in force output. The data analyzed for each trial did not include the first 4 s or the last 1 s of the trial.

3. Results

In order to assess the influence of one day of practice or competition on both outcome and nonlinear variables of force variability, the average of the first five trials of Day 1 were subtracted from the average of the first five trials of Days 2 and 3, yielding a difference score. Furthermore, the average of the first five trials of Day 2 was subtracted from the average of the first five trials of Day 3 to assess any further learning that occurred as a result of additional competition (Day 2). Comparison of performance at the beginning of each day gives us a measure of motor skill retention reflective of learning. An ANOVA was conducted with group (high task-high ego, low task-high ego, high task-low ego, and low task-low ego) and difference score (Day 2 – Day 1, Day 3 – Day 1, and Day 3 – Day 2) as factors. Confidence intervals were also calculated for each bar to note a significant difference from zero (indicating change from the start of one day to the start of the next).

For RMSE, there was no significant group, $F(3, 37) = 1.22, p = 0.32$, or difference score by group effect, $F(6, 74) = 0.83, p = 0.55$. There was a significant difference score effect, $F(2, 74) = 4.19, p = 0.02$ (Fig. 5), likely indicating lower values (greater improvement) over time. Both groups with high task performed significantly better on Day 2 versus Day 1 and on Day 3 versus Day 1. These findings were statistically supported using confidence intervals for the difference scores. The high task-high ego group had significantly negative RMSE for the difference between Days 1 and 2, CI $[-0.37, -0.10]$, and the difference between Days 1 and 3, 95% CI $[-0.46, -0.18]$. The high task-low ego group, likewise, had significantly negative RMSE for the difference between Days 1 and 2, CI $[-0.33, -0.005]$, and the difference between Days 1 and 3, 95% CI $[-0.54, -0.21]$. The only group to exhibit retained improvement on both Day 2 and Day 3 was the group with high task and low ego. The low task-high ego group also exhibited improvement from Day 1 to Day 2, 95% CI $[-.31, -.01]$, but did not show overall improvement from Day 1 to Day 3. The high task-low ego group had significantly negative RMSE for the difference between Days 2 and 3, 95% CI $[-0.37, -0.04]$. The low task-low ego group did not exhibit any difference in RMSE between the start of Days 2 and 1 or between the start of Days 3 and 1, 95% CI $[-0.33, -0.005]$; 95% CI $[-0.42, 0.10]$.

For SampEn, there were no significant group, $F(3, 37) = 1.52, p = 0.23$, or difference by group effects, $F(6, 74) = 0.56, p = 0.76$. There was a significant difference effect, $F(2, 74) = 5.88, p = 0.004$ (Fig. 6), likely reflecting the finding that no increase in SampEn was seen between Days 2 and 3. The groups with high task exhibited an increase in SampEn from Day 1 to Day 2 and from Day 1 to Day 3. The high task-high ego group had significantly positive SampEn for the difference between Days 1 and 2, 95% CI $[.02, 0.15]$, and the difference between Days 1 and 3, 95% CI $[.01, 0.15]$. The high task-low ego group, likewise, had significantly positive SampEn for the difference between Days 1 and 2, 95% CI $[.02, 0.18]$, and the difference between

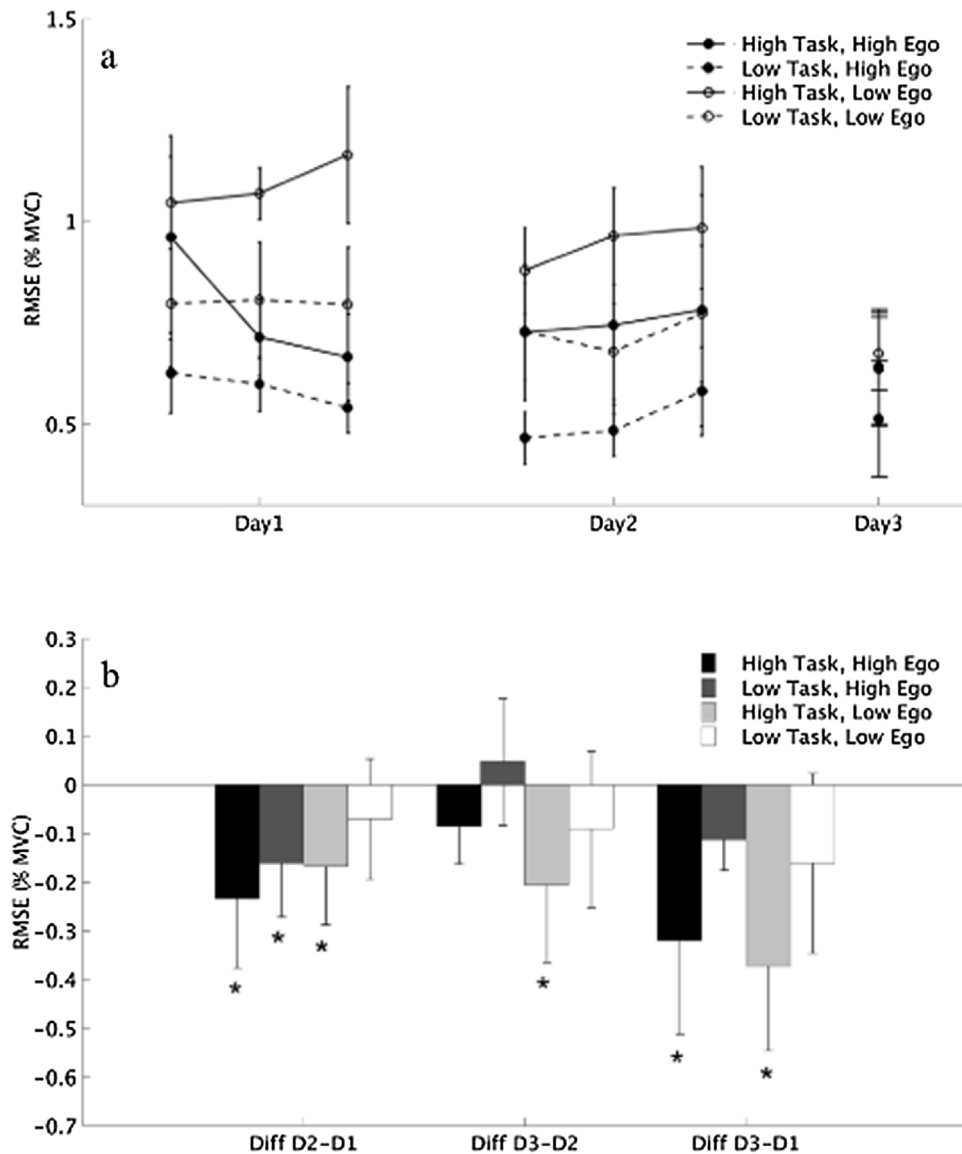


Fig. 5. a) Line plots for the three days of visual motor tracking. Each dot represents an average of 5 trials. The middle dot represents the middle 5 trials. b) Difference scores for RMSE for each motivational orientation group.

Days 1 and 3, 95% CI [.05, 0.21]. The group with low task and high ego orientation scores also exhibited increased SampEn from the beginning of Day 1 to the beginning of Day 2, 95% CI [.003, 0.15], but did not retain this increase from the beginning of Day 1 to the beginning of Day 3. The low task-high ego group had a significant decrease in SampEn between Days 2 and 3, 95% CI [-0.14, -0.00002].

In order to assess whether changes in non-linear aspects of performance were predictive of changes in linear aspects of performance, Pearson Product-Moment correlations were run on the difference values of RMSE and SampEn between Days 1 and 2, 2 and 3, and 1 and 3, respectively. A significant negative correlation was found between RMSE and SampEn for the difference between Day 3 and Day 2, $r(39) = -0.43$, $p = 0.005$, and the difference between Day 3 and Day 1, $r(39) = -0.46$, $p = 0.003$. No significant correlation was found for the difference between Day 2 and Day 1, $r(39) = -0.23$, $p = 0.14$.

4. Discussion

The aim of the present study was to document how differing motivational orientations, situated within environmental constraints (i.e., a practice and a competitive environment), influenced the nonlinear variability of performance and subsequent retention of a visual motor tracking skill. Participants performed an isometric force-tracking task that required them to trace a line representing a constant force value. Our first hypothesis, that greater irregularity of force variability would

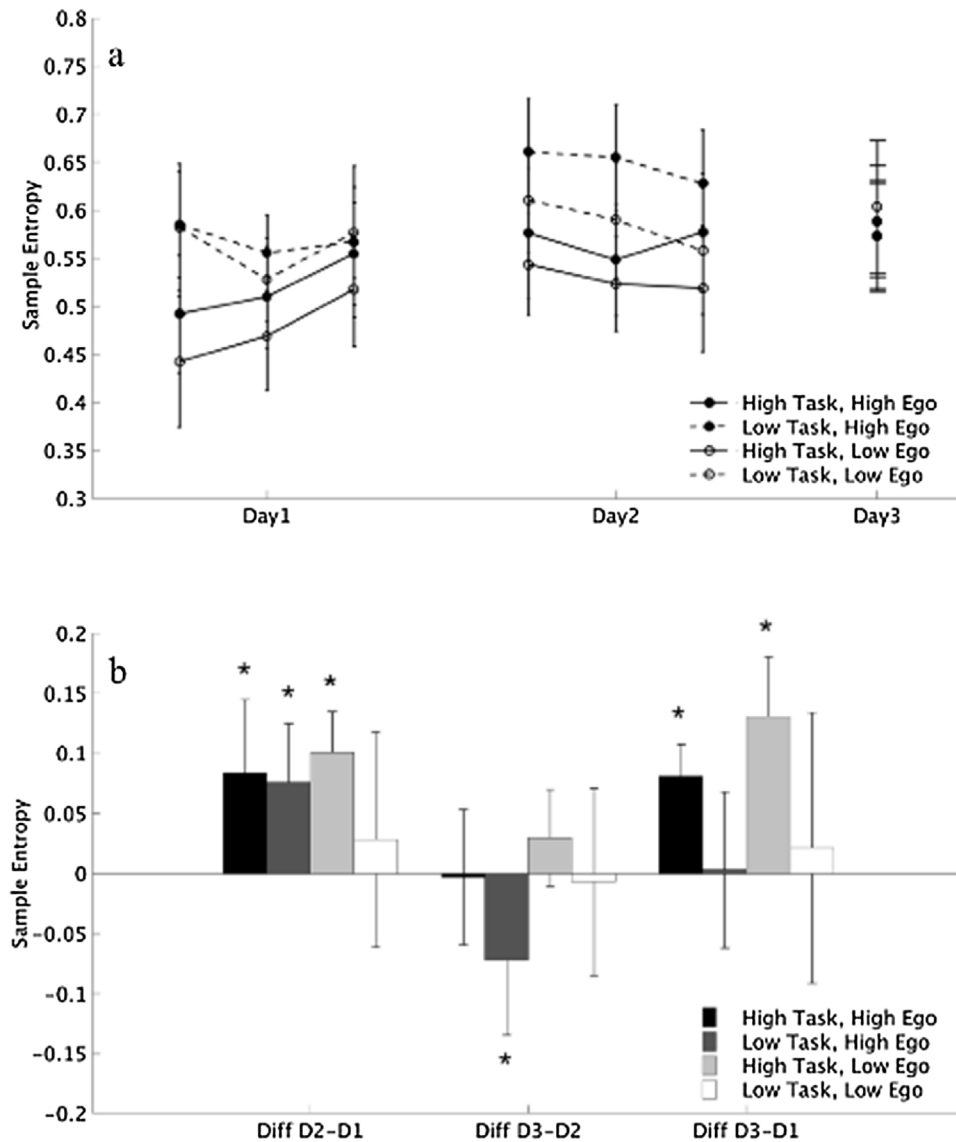


Fig. 6. a) Line plots for the three days of visual motor tracking. Each dot represents an average of 5 trials. The middle dot represents the middle 5 trials. b) Difference scores for Sample Entropy for each motivational orientation group.

reflect better overall performance and retention, was supported. Those who exhibited increased Sample Entropy from one day to the next also exhibited decreased RMSE (better performance outcomes). Sample Entropy – a measure of signal regularity – increased from Days 1–2 and was retained from Days 1–3 for those with high task orientation regardless of the level of ego orientation. This finding is in line with motor control research indicating that variability of practice leads to better learning and retention (Schmidt, 1975; Shea & Kohl, 1990; Van Rossum, 1990; Wrisberg & Liu, 1991). In this case, the variability exhibited by participants manifested as greater irregularity in continuous task performance. Greater irregularity is likely a result of the incorporation of multiple time scales into movement and may also reflect greater exploration of the task constraints (Stergiou & Decker, 2011; Vaillancourt & Newell, 2002). Furthermore, the finding of greater irregularity in visual motor performance over time for those with high task orientation supports seminal literature from sport psychology grounded in achievement goal theory (e.g., Duda, 1989). Namely, high perceived task orientation (regardless of perceived levels of ego orientation) led to a greater willingness to explore the environment at the risk of displaying mistakes.

Our second hypothesis, that individuals in the high-task, low-ego orientation profile would exhibit the greatest retention of visual-motor tracking, whereas individuals in the low-task, high-ego orientation would exhibit the least retention of a visual-motor tracking, was partially supported. Those with relatively high task orientation, regardless of the level of ego orientation exhibited both greater Sample Entropy and greater retention of improvements gained from practice. These findings highlight a previously unexplored link between motivational orientation and nonlinear aspects of motor output as

well as a link between the irregularity of a continuous motor task and retention of that task. Furthermore, these findings supplement findings from sport and exercise psychology, suggesting that individuals with high task orientation learn better and therefore may exhibit better overall performance in competitive settings. Collectively, these findings align with Dweck's more recent work attending to implicit theories (Dweck, 2011) and mindset theory (Dweck, 2008). These influential theories posit that individuals with a "fixed" mindset believe their innate qualities (e.g., intelligence or talent) are responsible for their success and failures. The net result of this mindset is a belief that talent creates success, often without effort – a primary characteristic of ego orientation within achievement goal theory. Conversely, individuals with a "growth" mindset believe that abilities are developed through dedication and disciplined work. The net result of this mindset is a love of learning and resilience in the face of failure – a primary characteristic of *task* orientation within achievement goal theory.

The vast majority of research in sport and exercise psychology links motivational orientation to perceptions of skill/ability rather than objective performance outcomes. Specifically, research has connected athletes' motivational orientations to perceptions of success, finding that higher skill (as rated by a team coach) corresponded to higher task orientation and perception of success related to hard work (Van-Yperen & Duda, 1999). Seminal work also describes young athletes high in task and ego orientation as maintaining higher perceptions of efficacy in the athletic domain (Horn, Duda, & Miller, 1993; see also Hodge & Petlichkoff, 2000). Another study found no link between motivational orientation and actual performance outcome (attaining a medal in a Chinese martial arts competition), suggesting that motivational orientation may influence perceptions of skill and or motivation to compete, but not performance directly (Kuan & Roy, 2007). Our findings show greater retention of a motor skill in groups with higher task orientation regardless of the level of ego orientation, suggesting high task orientation may buffer the potential negative impact of high ego orientation on learning. Due to the cross-sectional nature of the present study, however, it remains unclear whether high task orientation drives better overall performance, or whether better overall performance/skill competence drives task orientation to be higher.

Interestingly, only the high task/low ego group exhibited any learning following the competition (Day 2), but this learning was not paired with an increase in Sample Entropy. In fact, the only influence of competition on signal regularity was for the low task/high ego group, who showed a significant decrease in regularity from Day 2 (competition) to Day 3 (retention). This finding falls in line with research on song-birds demonstrating that during a form of competition – singing to a mate – variability of the fundamental frequency of song production decreases (Kao et al., 2005). It may be that, for humans, a decrease in regularity, influenced by personal motivational orientations, may, in fact, temper learning and retention gained during practice; however, the precise influence of practice versus competition cannot be determined under this study design.

5. Conclusions

In sum, the greatest benefits were seen during practice, and those benefits were retained only for the groups with high task orientation. The most well known literature regarding practice indicates that improvement in performance is determined by an individual's commitment to accumulating the requisite hours of "deliberate" practice. It has been hypothesized that if one designs and executes practice sessions in a deliberate fashion, improvement in performance will occur regardless of one's personal motivational orientation (Ericsson, Krampe, & Tesch-Römer, 1993). However, a recent meta-analysis disputes this claim and highlights several other psychological factors that may influence performance during competition (Macnamara, Hambrick, & Moreau, 2016). These factors included: confidence, aversion to negative outcome, and performance anxiety (Macnamara, Moreau, & Hambrick, 2016). Although, not directly mentioned in this review, motivational orientation might be an additional factor interacting with practice to influence performance during competition and retention of motor skill.

Ultimately, the present study has the potential to bridge the fields of motor control and sport and exercise psychology. Our interdisciplinary findings may have utility to a wide range of researchers and practitioners who aim to better understand the mechanisms associated with skill learning and retention in sport and non-sport settings. Indeed, as Lewin (1935) posited almost a century ago, understanding the interplay of person (e.g., motivational orientation) and environment (e.g., practice versus competition) characteristics may provide rich insight into an individual's behavior. Furthermore, understanding factors related to individual differences in the structure of variability and how these interact within different environmental constraints is crucial to understanding the nature of human behavior as a whole, especially in light of the growing use of nonlinear statistics to characterize task performance in both healthy and pathologic individuals (Ivanov et al., 1999; Rhea & Kiefer, 2014). Perhaps more interestingly, we have demonstrated for the first time a link between nonlinear aspects of continuous motor control (greater irregularity) during practice and competition and later retention of a continuous motor skill. This finding extends the extant literature on variability of practice (Schmidt, 1975; Schmidt & Lee, 2011) to performance of continuous motor tasks; both variability in practicing different iterations of the same task and practicing in different contexts (e.g., performing in different rooms or with different forces; Shea & Morgan, 1979) as well as variability in how one performs a continuous skill (greater irregularity in force output) improves long-term performance outcomes.

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