Learning and Motivation 58 (2017) 16–26

Contents lists available at ScienceDirect

Learning and Motivation

journal homepage: www.elsevier.com/locate/l&m

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

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ARTICLE INFO

Article history:
Received 2 March 2017
Accepted 3 March 2017

Keywords:
Motivational orientation
Retention
Nonlinear variability
Competition

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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http://dx.doi.org/10.1016/j.lmot.2017.03.002
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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.

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