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Changing one's focus of attention alters the structure of movement variability

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ABSTRACT

Substantial evidence supports the beneficial effect of an external (vs. internal) focus of attention on task performance during goal-directed movements. Counter-intuitively, an external focus has also been shown to increase joint-level movement variability.

Objective: To determine whether shifting attentional focus can alter the structure of movement variability, thereby offering a probable mechanistic explanation for how adopting an external focus of attention might confer its benefits.

Methods: Thirty-five healthy adults (age 23–55) performed unipedal hopping under three different attentional foci: natural (no directed focus), internal focus, and external focus. Uncontrolled manifold analysis was used to examine the structure of movement variability with respect to stabilization of leg orientation and vertical leg length during hopping. Takeoff/landing event bin and stance phase integrals of performance-irrelevant and performance-destabilizing variability were compared across focus conditions.

Results: Accuracy of hopping in place improved with both external and internal foci compared to the natural condition ($.004 \leq p \leq .035$). External focus, to a greater degree than internal focus, destabilized leg orientation at takeoff and landing compared to the natural condition ($.001 \leq p \leq .038$). External focus increased – but internal focus decreased – leg length stabilization throughout stance compared to the natural condition ($p < .001$).

Conclusion: External focus was superior to internal and natural focus conditions in terms of increasing flexibility within the system to orient the leg differently at takeoff and landing to compensate for unintentional drift during hopping. An external focus increased leg length stabilization in stance by preferentially increasing the subset of variability that explores multiple successful performance options. These results provide an understanding of the mechanism underlying external focus benefits – improving movement variability/coordination.

1. Introduction

There is a large body of literature that indicates adopting an external focus of attention benefits performance during goal-directed movements (see for review: Wulf, 2013; Wulf & Lewthwaite, 2016). An external focus directs the performer's attention to the effects of his/her movement within the environment, whereas an internal focus directs the performer's attention to details of the movement/action of their own body (Wulf, 2013). The performance benefits of an external (vs. internal) attentional focus have been demonstrated in several activities, including standing balance, jump height and distance, dart throwing accuracy, and basketball free throw

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shooting accuracy (Lohse, Jones, Healy, & Sherwood, 2014; Lohse, Sherwood, & Healy, 2010; Lohse & Sherwood, 2012; McNevin, Shea, & Wulf, 2003; Porter, Ostrowski, Nolan, & Wu, 2010; Rotem-Lehrer & Laufer, 2007; Wulf & Dufek, 2009; Wulf, Dufek, Lozano, & Pettigrew, 2010; Wulf, Landers, Lewthwaite, & Töllner, 2009; Wulf, McNevin, & Shea, 2001; Zachry, Wulf, Mercer, & Bezodis, 2005). Some studies also demonstrate a similar benefit of external focus over natural (undirected) focus (Lohse et al., 2014; Marchant, Clough, & Crawshaw, 2007; Wulf, Hob, & Prinz, 1998; Wulf & McNevin, 2003). Although the majority of these studies were performed with healthy participants, recent physical therapy literature has advocated for an external focus of attention, citing findings of improved balance-related measures in orthopedic and neurologic patient populations, and movement patterns associated with decreased injury risk in orthopedic patient populations (Gokeler et al., 2015; Landers, Wulf, Wallmann, & Guadagnoli, 2005; Laufer, Rotem-Lehrer, Ronen, Khayutin, & Rozenberg, 2007; Rotem-Lehrer & Laufer, 2007; Wulf et al., 2009).

While the majority of attentional focus studies report single-aspect performance measures, only a few studies have delved into measures that describe movement patterns resulting from verbal instructions in more depth (Gokeler et al., 2015; Lohse et al., 2014, 2010). Of particular relevance, a series of studies on throwing darts under an external focus demonstrated that there was an increase in kinematic variability at the joint level that accompanied improved accuracy and consistency of dart strike location (Lohse et al., 2014, 2010). For these studies, the methods were limited to single-joint kinematic variability, allowing only speculative discussion of intersegmental coordination or whole-limb level control.

Movement variability is often considered the result of an imperfect human movement system and therefore something to be minimized. However, variability is on display even in elite athletes and expert laborers (Bartlett, Wheat, & Robins, 2007; Bernstein, 1930; Davids, Glazier, Araújo, & Bartlett, 2003; Scholz, Schöner, & Latash, 2000). Furthermore, there is growing evidence that movement variability has positive roles (Davids et al., 2003; Glasgow, Bleakley, & Phillips, 2013; Hamill, Palmer, & Van Emmerik, 2012; James, Dufek, & Bates, 2000). These roles include providing multiple successful performance strategies for a task, making the performer adaptable to small changes in task, equipment, or personal state, and possibly even inoculating against injury (Davids et al., 2003; Glasgow et al., 2013; Hamill et al., 2012; James et al., 2000). The mechanism by which an external focus might both improve performance and increase variability as seen in the dart throwing studies discussed above has not been explored (Lohse et al., 2014, 2010).

Altered variability has been found in injured individuals as compared to their non-injured counterparts (Brach, Berlin, VanSwearingen, Newman, & Studenski, 2005; Brown, Bowser, & Simpson, 2012; Chiu & Chou, 2013; Chiu, Osternig, & Chou, 2013; Cote, Raymond, Mathieu, Feldman, & Levin, 2005; Cunningham, Mullineaux, Noehren, Shapiro, & Uhl, 2014; Heiderscheit, Hamill, & Van Emmerik, 2002; Jacobs, Henry, & Nagle, 2009; James et al., 2000; Miller, Meardon, Derrick, & Gillette, 2008; Moraiti, Stergiou, Ristanis, & Georgoulis, 2007; Seay, Van Emmerik, & Hamill, 2011; Selles, Wagenaar, Smit, & Wuisman, 2001). There is conflicting evidence in the literature, with some studies linking too much variability to pathology, while others link too little variability with pathology (Brach et al., 2005; Brown et al., 2012; Chiu & Chou, 2013; Chiu et al., 2013; Cote et al., 2005; Cunningham et al., 2014; Heiderscheit et al., 2002; Jacobs et al., 2009; James et al., 2000; Miller et al., 2008; Moraiti et al., 2007; Seay et al., 2011; Selles et al., 2001). These studies employed single- or dual-joint/segment measures of variability, which provide a magnitude of variability, but no descriptors of its quality – whether the variability promotes, or detracts from, performance consistency.

Uncontrolled manifold (UCM) analysis divides variability into performance-irrelevant (V_{UCM}) and performance-destabilizing (V_{ORT}) types (Latash, Scholz, & Schöner, 2007; Scholz & Schöner, 1999). By definition, V_{UCM}-type variability has no impact on the value of the performance- or task-level variable. For purposes of this study, any magnitude – small or large – of V_{UCM}-type variability allows for a consistent leg orientation or leg length during hopping. V_{ORT}-type variability, by definition, leads to inconsistency in a performance- or task-level variable. The larger the magnitude of V_{ORT}-type variability, the less consistent the leg orientation or leg length during hopping.

It logically follows that V_{UCM}-type rather than V_{ORT}-type variability plays the positive role of providing adaptability and protection against injury *without* disrupting performance. Insufficient V_{UCM}-type variability may indicate an overly-stereotyped manner of performance. This matches with prior UCM analyses demonstrating that aging and neurological disorder are associated with a lesser proportion of V_{UCM} compared to V_{ORT} (Kapur, Zatsiorsky, & Latash, 2010; Park, Jo, Lewis, Huang, & Latash, 2013). Failing to exploit redundancies in the movement system to explore the many and varied successful versions of performance may plausibly predispose one to overload a particular joint or tissue, especially when performing repetitive tasks. UCM analysis has proven sensitive to the effects of practice, external perturbation, changes in mechanical demand or task difficulty, and fatigue, indicating it will likely also be responsive to the effects of attentional focus instruction (Auyang & Chang, 2013; de Freitas, Scholz, & Stehman, 2007; Latash, 2012; Mattos, Latash, Park, Kuhl, & Scholz, 2011; Scholz & Schöner, 1999; Wu & Latash, 2014).

UCM analysis offers a promising tool to understand the probable mechanism underlying the ability of verbal instructions – particularly with regard to attentional focus – to provide performance benefits by altering the structure of variability. UCM analysis requires a large number of trials and is therefore particularly well suited to naturally repetitive or continuous tasks, rather than repetitions of a discrete task. This study examines movement variability with UCM during hopping in place, a tightly controlled proxy for other ecologically relevant bouncing gaits such as running.

When asked to hop in place, it is intuitive that the control system would try to stabilize leg orientation around the times of takeoff and landing. Leg orientation at takeoff affects the center of mass trajectory into flight. Leg orientation at landing affects center of mass position respective to the base of support. If the leg is oriented too far in front of – or behind –the pelvis, the center of mass will be outside the base of support. This will lead to backward or forward progression respectively, or in an extreme case, a fall. A previous study examined the effect of foot placement constraint (decreasing hop location target-size) on the control of leg orientation in unipedal hopping (Auyang & Chang, 2013). Increased stabilization of leg orientation throughout the entire hop cycle with smaller (vs. larger) hop location target size was demonstrated (Auyang & Chang, 2013). For the present study, the variables for UCM analysis