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Differences in motor variability among individuals performing a standardized short-cycle manual task

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ABSTRACT

Motor variability (MV) has been suggested to be a determinant of the risk for developing musculoskeletal disorders in repetitive work. In this study we examined whether individuals consistently differed in the extent of motor variability when performing a standardized short-cycle manual task. On three separate days, arm kinematics was recorded in 14 healthy subjects performing a pipetting task, transferring liquid from a pick-up tube to eight target tubes with a cycle time of 2.8 s. Cycle-to-cycle standard deviations (SD) of a large selection of shoulder and elbow kinematic variables, were processed using principal component analysis (PCA). Thereafter, between-subjects and between-days (within-subject) variance components were calculated using a random effects model for each of four extracted principal components. The results showed that MV differed consistently between subjects (95% confidence intervals of the between-subjects variances did not include zero) and that subjects differed consistently in MV between days. Thus, our results support the notion that MV may be a consistent personal trait, even though further research is needed to verify whether individuals rank consistently in MV even across tasks. If so, MV may be a candidate determinant of the risk of developing fatigue and musculoskeletal disorders in repetitive occupational work.

1. Introduction

As pointed out by Bernstein 50 years ago (Bernstein, 1967), no particular movement is ever repeated with exactly the same movement trajectory, regardless of the extent of practice, experience, or skill of the subject performing the movement. This intra-individual motor variability (MV), defined as a spatiotemporal dispersion in joint movements, coordination and muscle activities between successive repeats of the same task, has traditionally been seen as undesirable performance inconsistencies or errors, reflecting immature or insufficient sensorimotor functioning. However, more recent research emphasizes positive functional aspects of MV, with respect to both long-term motor learning and short-term adaptations of movement strategies (e.g., Davids, Glazier, Araujo, & Bartlett, 2003; Latash, Scholz, Danion, & Schoner, 2002; Wu, Truglio, Zatsiorsky, & Latash, 2015). Thus, MV has been suggested to be essential for maintaining performance under

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changing environmental conditions, for adapting to changes in the musculoskeletal system during growth, and for permitting exploration of constraints in the task or environment, so that stable motor solutions can develop over time (e.g., Newell, Deutsch, Sosnoff, & Mayer-Kress, 2006; Newell & Vaillancourt, 2001; Riley & Turvey, 2002).

The functional role of MV has been emphasized also in occupational and clinical research (Srinivasan & Mathiassen, 2012). Repetitive work, where similar operations are repeated again and again (e.g., Kilbom & Persson, 1987), is a generally accepted risk factor for musculoskeletal disorders in the shoulders and upper extremities (Cote et al., 2008). Since increased posture and movement variability may potentially distribute stresses better between tissues, and thus reduce the cumulative load on specific tissues, MV could play a significant functional role in delaying or preventing acute fatigue and development of chronic musculoskeletal disorders (MSD; e.g., Mathiassen, 2006; Srinivasan & Mathiassen, 2012). Theories like the "Cinderella recruitment hypothesis" (Hägg, 1991), and the "Variability-overuse hypothesis" (reviewed in Bartlett, Wheat, & Robins, 2007), have further detailed why highly stereotyped motor behavior may increase the risk of developing MSDs. The Cinderella hypothesis states, on basis of Henneman's theory of a size-ordered recruitment of motor units with increasing contraction force (Henneman, Somjen, & Carpenter, 1965), that some low-threshold motor units will be activated as soon as the muscle contracts, and stay active during monotonous work until total rest, with increased risk for overuse of these, primarily, small sized (type I) muscle fibers. Thus, the Cinderella hypothesis implies that spatial and temporal variation in muscle recruitment is needed to alleviate risk. The variability-overuse hypothesis essentially conveys the same message, i.e. that lack of variation in postures and muscle recruitment can lead to overuse injuries.

While all individuals repeat a particular task with some MV, the extent of this variability appears to differ between individuals (e.g., Hammarskjold, Harms-Ringdahl, & Ekholm, 1990; Mathiassen, Moller, & Forsman, 2003; Srinivasan, Rudolfsson, & Mathiassen, 2015; van Dieen, Dekkers, Groen, Toussaint, & Meijer, 2001). In studies of work and sports, MV has been shown to be associated with the skill level of the individual (e.g., Madeleine & Madsen, 2009; Robins, Wheat, Irwin, & Bartlett, 2006), and it changes as a natural part of skill development (e.g., Gentile, 1972; Vereijken, Emmerik, Whiting, & Newell, 1992). Other individual factors known to influence MV are, for example; age (e.g., Kruger, Eggert, & Straube, 2013), gender (e.g., Svendsen & Madeleine, 2010), chronic pain (e.g., Madeleine, Mathiassen, & Arendt-Nielsen, 2008), and body composition (e.g., Chiari, Rocchi, & Cappello, 2002). Women typically exhibit lower MV than men, and older people lower MV than younger. Notably, Madeleine et al. (2008) found that acute experimental pain *increased* arm movement MV, presumably because subjects explored alternative motor solutions to reduce pain, while chronic pain was associated with *reduced* MV, interpreted to reflect an attempt to avoid painful movements and postures (Madeleine et al., 2008). However, consistent differences in MV between individuals are likely to occur even in populations that are rather homogeneous with respect to these factors. Motor behavior largely depends on anatomical and physiological constraints known to differ between individuals even if they have the same gender, age and health status, such as muscle strength, flexibility and sensory capacities. Also psychological traits and processes have a bearing on motor behavior. Recent MRI studies of the human brain suggest that individual differences in several basic and higher cognitive functions, including, for example; perception, motor control, memory, and the capacity for introspection can be predicted from the structural anatomy of the brain and so appearing to be stable individual attributes (reviewed in Kanai & Rees, 2011; MacDonald, Nyberg, & Backman, 2006). Hence, long-standing differences among individuals in physical and cognitive abilities, formed by genetics and lifetime experience, suggest consistent differences also in motor behavior, including motor variability. However, very few empirical studies, if any, have verified whether individuals in a homogeneous population with respect to gender, age and health do, indeed, differ consistently in MV, even after taking into consideration that any particular individual will vary in her motor patterns when performing a specific task several times within a day, as well as when performing on different days (Bernstein, 1967; Rabbitt, Osman, Moore, & Stollery, 2001). The issue of whether healthy subjects populating a particular job or enterprise differ consistently in MV is of high relevance in an occupational health context. Some evidence suggests that individuals with larger MV may be less prone to fatigue (Falla & Farina, 2007; van Dieen, Oude Vrielink, & Toussaint, 1993), and pain (Madeleine & Madsen, 2009), and that they may recover faster from injury (Moseley & Hodges, 2006). In extension, this could imply that individuals performing repetitive work with a larger MV would be less at risk of developing MSD than individuals performing the same tasks with less MV (Madeleine, 2010; Mathiassen, 2006).

Assessment of MV can be performed on different levels. Both higher level aspects of movement performance (kinematics, kinetics), and lower level aspects (muscle activation) provide unique perspectives, and they are usually modelled separately. Investigations of muscle activity are relevant in the context of musculoskeletal disorders, and some studies have, indeed, addressed both kinematics and muscle activity in occupationally relevant tasks (e.g., Bosch, Mathiassen, Visser, de Looze, & van Dieen, 2011; Madeleine, Mathiassen et al., 2008; Madeleine, Voigt, & Mathiassen, 2008). However, a challenge when investigating MV in complex multi-joint movements is the multitude of muscles involved, and the extensive redundancy both within and between muscles that needs to be identified and analyzed. Consequently, registrations of surface EMG are of limited use for more delicate studies of MV on a muscle activation level in dynamic movements like reaching. Most current models of motor control, however, assume encoding of high-level parameters of motor behavior such as velocity and position of the effector, rather than detailed specification of muscles (Shumway-Cook & Woollacott, 2012). A focus on kinematic aspects may therefore provide more realistic and applicable models of human movement behavior in dynamic multi-joint movements.

Kinematic analysis typically involve a large number of recordings and measurements such as displacements, velocities and acceleration of joints and segments. In previous work of the task addressed in the present paper we have reported day-to-day (within subject) and between-subjects variances for several metrics describing motor variability (Samani,