Human Movement Science 32 (2013) 540–554

Contents lists available at SciVerse ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

The smoothness of unconstrained head movements is velocity-dependent

Harald Vikne [a,*], Eva Sigrid Bakke [a], Knut Liestøl [b], Gunnar Sandbæk [c], Nina Vøllestad [a]

[a] Department of Health Sciences, Institute of Health and Society, University of Oslo, P.O. Box 1089, Blindern, N-0317 Oslo, Norway
[b] Department of Informatics, University of Oslo, P.O. Box 1080, Blindern, N-0316 Oslo, Norway
[c] Department of Radiology and Nuclear Medicine, Oslo University Hospital – Aker, P.O. Box 4959, Nydalen, N-0424 Oslo, Norway

ARTICLE INFO

Article history:

PsycINFO classification:
2221

Keywords:
Head kinematics
Movement smoothness
Movement velocity
Submovements
Normalized jerk cost

ABSTRACT

Non-smooth, irregular movements reported in persons with neck pain have been suggested to signify motor impairment. However, irregular movements are additionally observed during slow movements in healthy participants. We therefore examined whether the smoothness of head movements is related to the movement speed in 26 healthy participants. Six unconstrained small and large amplitude head movements were completed in the sagittal plane at three different self-chosen speeds. Kinematic variables were calculated from position data and overall smoothness of the movement was assessed by the normalized jerk cost (NJC). Relationship between NJC and average movement angular velocity was analyzed using a mixed factor model. Movement duration, angular velocity, NJC and number of submovements differed significantly between speed conditions for all movement directions and amplitudes (all $p < .05$). We found a strong relationship between the average angular velocity and NJC across all movement directions and amplitudes (all $p < .0001$). Large amplitude movements showed higher NJC for a given movement velocity than small amplitude movements ($p < .001$). We have shown that the smoothness of head movements is strongly related to the movement velocity, thus fast movements are smooth while slow movements are jerky. In addition, movements of larger amplitude are less smooth than movements of smaller amplitude.

* Corresponding author. Tel.: +47 22845382; fax: +47 22845091.
E-mail address: haralv@medisin.uio.no (H. Vikne).

0167-9457/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.humov.2012.12.013

1. Introduction

Natural, unconstrained voluntary movements in humans are normally smooth and exhibit a near symmetrical, bell-shaped velocity profile containing a single velocity peak with approximately equally long acceleration and deceleration phases. Such profiles have been reported in studies addressing movements such as reaching, pointing and grasping and across several species (Aflalo & Graziano, 2007; Alstermark, Lundberg, Pettersson, Tantisira, & Walkowska, 1993; Atkeson & Hollerbach, 1985; Ostry, Cooke, & Munhall, 1987; Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1990). When temporal or spatial accuracy constrains are introduced, the movements become less smooth, and irregularities in the velocity profiles have been reported across various species (Milner & Ijaz, 1990; Roitman, Massaquoi, Takahashi, & Ebner, 2004; Thompson, McConnell, Slocum, & Bohan, 2007). The irregularities within the movements have been suggested to be submovements, appearing as down scaled, bell-shaped velocity peaks (Crossman & Goodeve, 1983; Krebs, Aisen, Volpe, & Hogan, 1999; Milner, 1992).

Movements of patients with neurological injury and diseases are less smooth compared with healthy controls and are characterized by submovements within the velocity profile (Rohrer et al., 2002; Smith, Brandt, & Shadmehr, 2000; Teulings, Contreras-Vidal, Stelmach, & Adler, 1997; Tsao & Mirbagheri, 2007). Also in musculoskeletal neck pain, movements are shown to be less smooth and more irregular compared with controls without pain (Feipel, Rondelet, LePallec, DeWitte, & Rooze, 1999; Grip, Sundelin, Gerdle, & Karlsson, 2008; Sarig Bahat, Weiss, & Laufer, 2010; Sjölander, Michaelson, Jaric, & Djupsjöbacka, 2008). Consequently, increased irregularity and reduced smoothness of movement as compared to control situations have been considered a sign of altered motor behavior and impaired motor performance (Sjölander et al., 2008; Smith et al., 2000; Teulings et al., 1997).

However, it has been observed in healthy participants that when relatively unconstrained movements are completed with reduced velocity, irregularities appear on the velocity tracings (Darling, Cole, & Abbs, 1988; Milner, 1992; Milner & Ijaz, 1990; Morasso, Ivaldi, & Ruggiero, 1983). For example, Morasso et al. (1983) noted that while planar pointing movements performed at natural speed displayed a single peaked velocity profile, more velocity peaks appeared at slower movements. Similarly, in a time-constrained pinching task, Darling et al. (1988) reported that while 100 ms movements of the thumb and index finger were completed with a single submovement, 200–400 ms pinches contained a series of submovements. Although no statistical analysis of smoothness or irregularity between movements velocities were completed in either of these studies, the descriptions of increased irregular velocity profiles at relatively slow movements imply a relationship between movement velocity and smoothness. Using spatio-temporal constrained arm movements, van der Wel, Sternad, and Rosenbaum (2009), found an overall statistically significant effect of standardized movement times on the number of velocity peaks within a movement. Although the accuracy constraints in their study were relatively limited, the arm movements were completed in a continuous, rhythmic mode and paced by a metronome, which previously has been reported to reduce movement smoothness as compared to unpaced movements (Balasubramaniam, Wing, & Daffertshofer, 2004). Thus, these results accomplished for constrained movements may not directly apply to unconstrained movement. Although the above studies strongly suggest that a relationship between movement smoothness and velocity exist, to our knowledge, no statistically based evaluation of such a relationship in simple, unconstrained movements have been published. Of particular interest was to examine a relationship between smoothness and velocity in head and neck movements. As noted above, these movements are previously reported to be less smooth in humans with musculoskeletal neck pain as compared to unimpaired controls and this finding has been interpreted as a sign of altered motor control. However, since these movements were reported to be less fast and have less amplitude than for unimpaired control participants (Grip et al., 2008; Sarig Bahat et al., 2010), we wanted to examine whether the movement velocity and amplitude could be main sources of irregularity in head movements.

The goal of this study was thus to examine the relationship between movement smoothness and velocity of unconstrained movements in healthy human participants, and particularly to consider the case of head movements. We tested the hypothesis that overall movement smoothness is related