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Differences in muscle activity patterns and graphical product quality in children copying and tracing activities on horizontal or vertical surfaces

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ABSTRACT

The observation that a given task, e.g. producing a signature, looks similar when created by different motor commands and different muscles groups is known as motor equivalence. Relatively little data exists regarding the characteristics of motor equivalence in children. In this study, we compared the level of performance when performing a tracing task and copying figures in two common postures: while sitting at a desk and while standing in front of a wall, among preschool children. In addition, we compared muscle activity patterns in both postures. Specifically, we compared the movements of 35 five- to six-year old children, recording the same movements of copying figures and path tracing on an electronic tablet in both a horizontal orientation, while sitting, and a vertical orientation, while standing. Different muscle activation patterns were observed between the postures, however no significant difference in the performance level was found, providing evidence of motor equivalence at this young age. The study presents a straightforward method of assessing motor equivalence that can be extended to other stages of development as well as motor disorders.

1. Introduction

Motor equivalence is the similarity of movements produced by different sets of motor commands, utilizing different muscle groups (Sporns and Edelman, 1993; Wing, 2000), for example, when signing one's name on a piece of paper or signing it in larger letters, on a blackboard (Merton, 1972). Although different muscles are used to produce the two movements, the graphical product has been found to be similar. This is considered natural in adults; however, motor coordination develops gradually during childhood, as variations in neural and biomechanical structures evolve in the child (Sporns and Edelman, 1993). There is a scarcity of studies that investigate the characteristics of motor equivalence in children. An early study comparing speech-motor equivalence in children, adults and elderly individuals showed that young children and elderly individuals have a similar muscle activity pattern, which differs from that of adults, and which consequently results in alterations of rate and precision of speech (Rastatter et al., 1987). However, the effect of using different muscles to obtain a similar graphical goal in children, e.g. copying a circle, has yet to be investigated. The instruction for children to produce graphic products under different conditions, e.g. using different tools or inclined surfaces, is a common activity in kindergartens and schools. Also, children having difficulties in acquiring graphomotor skills are instructed by occupational therapists to draw on a vertical surface (Amundson, 1992; Judge, 2006), under the unsubstantiated assumption that in this position, the wrist is fixated in a functional drawing position and that shoulder stability is practiced (Benbow, 1995).

Motor equivalence is related to the notion of context-conditioned variability (Turvey et al., 1982). Even when repeating the same task in the same posture, the precise context (e.g. posture, muscle activations, fatigue) is always different between repetitions. These differences mean that the solution for performing the same task also must differ between repetitions. The observation that we produce similar outputs (e.g. when drawing) despite these differences in context implies that the motor programs we use are unlikely to take the form of the muscle contractions necessary to perform a task. Rather, at the muscle and joint level we expect to see significant variability in performance due to these differences in context. In a well-tuned system, we expect that this variability in muscle activations will not, however, lead to significant differences in task performance.

Movements produced in different planes (i.e. horizontally and vertically) are subject to different constraints. For example,

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movements in the vertical plane must deal with the effect of gravity which may modify the dynamics of the movement (Atkeson and Hollerbach, 1985). Further, this posture of the hand is related to proximal motor function, i.e. the shoulder and upper arm, rather than distal motor function, i.e., the wrist and fingers. Proximal function has been considered to be a prerequisite for distal function and manipulative hand use (Heriza, 1991), although empirical findings revealed that these two systems might be independent of each other, and relate to different types of control (Naider-Steinhart and Katz-Leurer, 2007). Although clinical experience has implied positive outcomes on grasp when using the upright position of the hand while working on a vertical surface, few empirical studies support this premise. For example, a study with 2-year old infants given a crayon, a pencil, or a marker found that only for the crayon, a more mature grasp was used with an upright easel rather than drawing flat on the table (Yakimishyn and Magill-Evans, 2002), although the level of performance was not evaluated in their study. The lack of studies in this area led us to examine how performance differs between similar tasks performed by children on different surfaces with different body postures.

The objectives of this study were firstly to assess the level of performance of a tracing task and a copying figures task in two common postures, while sitting at a desk and while standing in front of a wall, among preschool children. By comparing muscles activity patterns, we can confirm that the tasks are performed differently in the two postures. Based on our knowledge of motor equivalence, we predicted that the level of performance in both cases would be similar. Despite this, we expected that the proximal muscles will be more activated and fatigued (in longer tasks) while drawing on the vertical surface in a standing position.

2. Methods

2.1. Study design

This was a repeated-measures study, with the inclination of the surface as the independent variable.

2.2. Participants

Thirty five right-hand dominant healthy children (17 boys, 18 girls; mean and SD age of 5.9 ± 0.4 years) participated in this study. Inclusion criteria were healthy five- to six-year old children. Exclusion criteria were any orthopedic or neurologic impairment, visual impairment that could not be corrected with glasses, or ability to understand and follow simple instructions, reported by the parents. All participants were enrolled in fulltime preschool programs and recruited through personal contact and snowball sampling. The study was approved by the Occupational Therapy Department Ethics Committee at the research facility.

2.3. Research tools and protocol

The parents signed an informed consent form and each subject was administered the long form Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery VMI), frequently administered during visual perceptual evaluations (Beery, 1997), during which the subject copies basic shapes. The subjects were divided into two groups, matched according to the percentile ranks of this test (mean and SD: Group 1: 59.6 ± 22.4, group 2: 60.9 ± 22.4; $p = 0.63$). A repeated measure design with counter-balanced order of two conditions was used, with half the participants first tested with the horizontal orientation and then the vertical orientation and the other half tested in the reverse order, to eliminate the effect of learning.

Parts of the Fine Manual Control subtest of the Bruininks-Oseretsky Test of Motor Proficiency (BOT2) (Deitz et al., 2007) were recorded with a digital tablet (Samsung Galaxy Note 10.1 GT-N8010) using an 11.5 cm long stylus provided with the tablet. This tablet has a built-in Wacom digitizer, with a manufacturer specified resolution of 0.01 mm. Specifically, the subjects had to copy four shapes (circle, square, star and wave); and complete two path tracing tasks between two lines (broken or curved paths) – see Fig. 3 for the stimuli. The location of the tip of the stylus on the tablet was recorded at 125 Hz (determined based on the collected data) using custom Android software (available by request from the corresponding author), and was analyzed using custom code (Matlab R2012b, MathWorks, Natick, MA, USA). The raw data were filtered using a 2nd order two-way low-pass Butterworth filter (i.e. effectively a 4th order filter), with a cut-off of 5 Hz. The tablet was set in a wooden frame (Fig. 1), to allow the height of the tablet and frame to be equal. A stand was built to hold the frame in a vertical position, when required and clips were used to secure the tablet when positioned vertically.

A telemetric surface electromyography (sEMG) system (Myon RFTD, Myon AG, CH) with a floating ground and pairs of bipolar Ag/AgCl surface electrodes (Ambu Blue Sensor N-Electrodes, Denmark) was used to measure activity of the upper trapezius (UT), biceps brachii (BB), and extensor carpi radialis (ECR), chosen for their major role during fine dexterity tasks (Linderman et al., 2009; Sporrong et al., 1998). Skin preparation and electrode placement were done according to the sEMG for a non-invasive assessment of muscles (SENIAM) guidelines (Hermens et al., 2000). The electrodes were placed parallel to the general axis of the muscle fibers, with a center-to-center inter-electrode constant distance of 20 mm and remained on the skin throughout the duration of the trial. The system comprises of analogue differential amplifiers and the sEMG signals were amplified no further than 10 cm from the recording site. Data were collected at a sampling rate of 1000 Hz and bandpass filtered (dual-pass 2nd order Butterworth, 10–500 Hz). Data were acquired and analyzed using custom code (LabView V12, National Instruments, Austin, TX, USA). In order to permit amplitude normalization of sEMG data, the subjects performed several maximum isometric voluntary contractions (MVCs) for five seconds for each of the monitored muscles (Burden, 2010; Frost et al., 2012). Recording was initiated following explanation and practice by the subject. The signals were displayed on the computer while acquiring the MVC data in order to provide biofeedback to the subject to elicit a maximal contraction. Further, verbal encouragement was provided by the researcher.

Each subject was asked to copy the four shapes and perform the path tracing tasks twice: once when the tablet was positioned horizontally on the table, during which the subject was seated on a chair, fitted to his or her height. The subject was able to rest the elbow or wrist on the table, but no verbal instruction was provided so that each subject performed the task at his or her on convenience. Each subject repeated the task when the tablet was positioned vertically, and the subject stood in front of it (the center of the tablet was positioned in front of the midline of the subject and the subject was asked to stand at a comfortable distance). The task under each condition, horizontal or vertical, lasted approximately two to three minutes and the subjects were instructed to sit and rest their arm while the tablet was arranged for the following setup.

2.4. Post analysis

2.4.1. Graphical product quality

As the tablet only records when the stylus touches the tablet, movement start and end were determined from the first and last time the stylus touched the tablet. The movement time was