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Dynamic touch is affected in children with cerebral palsy

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ABSTRACT

Children with developmental disorders such as cerebral palsy have limited opportunities for effortful interactions with objects and tools. The goal of the study was to investigate whether children with cerebral palsy have deficits in their ability to perceive object length by dynamic touch when compared to typically developing children. Fourteen children with typical development and 12 children with cerebral palsy were asked to report the length of hand-held rods after wielding them out of sight. Multilevel regression models indicated that I_1 (maximum principal moment of inertia) was a significant predictor of perceived length – L_P ($p < .0001$). The effect of I_1 on L_P was significantly different among children ($p = .001$) and the presence of cerebral palsy (group factor) partially explained such variance ($p = .002$). In addition, accuracy and reliability of the length judgments made by children with cerebral palsy were significantly lower than the typically developing children ($p < .05$). Theoretical and clinical implications of these results were identified and discussed.

1. Introduction

Many daily and sports activities involve actions in which individuals interact with objects and tools. Performance of such activities relies heavily on the functioning of the haptic perceptual system,

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particularly the haptic subsystem of dynamic touch. The haptic subsystem of dynamic touch (traditionally known as the muscle sense) is sensitive to information about the properties of hand-held objects that determines the patterning, timing and magnitude of the arm's muscular forces required to accomplish an intended function (Pagano, Fitzpatrick, & Turvey, 1993). Therefore, deficits in this form of perception might be related to deficient performance of actions—both ordinary and skilled—observed in individuals with sensory and motor impairments associated with a number of clinical conditions.

Despite of relevance of dynamic touch, the kinds of changes in this perceptual subsystem that accompany movement impairments are only beginning to be uncovered (Carello, Silva, Kinsella-Shaw, & Turvey, 2008; Silva, Harrison, Kinsella-Shaw, Turvey, & Carello, 2009). Studies to date suggest that dynamic touch is generally more robust to insults to both sensory and motor systems than other forms of touch, as cutaneous and haptic touch (Carello, Kinsella-Shaw, Amazeen, & Turvey, 2006; Carello et al., 2008; Silva et al., 2009). The present investigation is an initial attempt to understand the basis for this apparent robustness and to uncover clinical conditions under which deficits might arise.

1.1. The exploration-information mutuality

The information (moment of inertia[1]) that supports the perception of object's properties (e.g., length) can only be revealed when one attempts to accelerate an object in different directions (Carello & Turvey, 2000; Michaels & Isenhower, 2011). This indicates that the haptic subsystem of dynamic touch relies on information that is only revealed by means of effortful hand-object interactions that underlies many functional activities (Carello et al., 2008; Turvey, 1996). The sensitization (or attunement) to an informational parameter, that supports perception of a particular property by dynamic touch, necessarily presupposes active exploration that reveals such parameter, that is, information and exploration are mutually co-implicated (Gibson, 1963, 1969, 1966).

The exploration-information mutuality was demonstrated in haptic and dynamic contexts. Lederman and Klatzky (1987) demonstrated that, in the context of haptic perception, hand movements vary with the to-be-detected information. In this case, different exploratory patterns were used when the individual sought for information about texture versus information about hardness of an object (Lederman & Klatzky, 1987). In the context of dynamic touch, the influence of action on information detection and perception of object properties was investigated by Amazeen, Tseng, Valdez, and Vera (2011). These authors demonstrated that perceivers lifted objects in order to generate the information on heaviness perception and that this perception was influenced by the style of lifting. Riley, Wagman, Santana, Carello, and Turvey (2002) demonstrated that different exploration patterns were observed when individuals were asked to perceive different properties (e.g., width versus length) of an object (Riley et al., 2002). Specifically, invariant patterns of exploration, defined over varied kinematic strategies (e.g., move in quite distinct spatial temporal trajectories, apply distinct torques, use different joints), seem to created a transformation of the object required to reveal information supporting the perception (Arzamarski, Isenhower, Kay, Turvey, & Michaels, 2010).

The co-implication of intention, information, and exploration has been formalized in a theoretical proposition that became known as the co-specificity hypothesis (Turvey, Carello, & Kim, 1990). This hypothesis implies that the intention to perceive a particular object property entails a particular

[1] The moment of inertia (the second moment of the object's mass moments) represents the object's resistance against angular acceleration around a specific axis and depends on the mass and its distribution (distance between center of mass and point of rotation – $I = mL^2$). The object's resistance against angular acceleration in different directions is quantified by the inertia tensor (I_{ij}). The tensor of inertia (mathematically represented by 3×3 symmetric matrix) is an invariant that relate the torques and motions produced by physical properties of the object and the movements of the segment that wielded it. The diagonal elements of the tensor represent the magnitudes of resistance to rotation in the three orthogonal axes (moments of inertia: Ixx, Iyy, Izz). The elements located off the diagonal quantify the resistance to rotation in directions perpendicular to the rotation axes (products of inertia: I_{xy}, I_{xz}, I_{yz}), indicating the asymmetry of the object's mass distribution. The diagonalization of the tensor allows obtaining the principal moments of inertia or eigenvalues (I_1, I_2, I_3: maximal, intermediate and minimal moments of inertia, respectively) and their respective orientation or axes of symmetry (eigenvectors: e_1, e_2, e_3). The maximal moment of inertia (I_1) has been implicated as informational basis for length perception of objects of equal diameter and density. In these cases, the perceived length is a single valued power function of the I_1, with a scaling exponent of 1/3. For details about inertial properties calculations and information basis for dynamic touch see Fitzpatrick, Carello, and Turvey (1994) and Carello and Turvey (2000).