Research in Developmental Disabilities 35 (2014) 2416–2422

Contents lists available at ScienceDirect

Research in Developmental Disabilities

Bimanual coordination in typical and atypical infants: Movement initiation, object touching and grasping

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ARTICLE INFO

Article history:
Received 8 April 2014
Received in revised form 29 May 2014
Accepted 29 May 2014
Available online

Keywords:
Reaching
Grasping
Interlimb coordination
Down syndrome
Object properties

ABSTRACT

The development of bimanual actions reflects perceptual, motor and cognitive processes, as well as the functional connectivity between brain hemispheres. We investigated the development of uni- and bimanual actions in typically-developing (TD) infants and infants with Down syndrome (DS) while they reached for objects with varying sizes. Eight TD infants and seven infants with DS (ages 4–8 months) were tested at several stages of reaching experience. Movement strategies at movement initiation, object touching and grasping were recorded. With reaching experience, typical infants increased ability to anticipate reaching strategies, and independent use of the hands according to task demands. Strategies used by infants with DS were mostly compensatory rather than anticipatory, and showed a weaker tendency for interlimb coupling at early ages. These differences may underlie functional limitations, and should be subject to early intervention.

1. Introduction

Typically-developing infants start to reach around 3-4 months of age (Thelen et al., 1993; Von Hofsten, 1991). By the time of reaching onset, infants frequently use bimanual strategy with the arms in synchronized and symmetric trajectories (Corbetta & Thelen, 1996; Fagard & Jacquet, 1996). The ability to select uni- or bimanual reaches based on object properties is progressively refined (Rocha, de Campos, Silva, & Tudella, 2012), and asymmetrical bimanual manipulation of objects becomes prominent at later ages.

While early reaches show a strong innate tendency for interlimb coupling (Cardoso de Oliveira, 2002), the maturation of interhemispheric connections seems to be related to emergency of asymmetrical manipulation of objects, which is rudimentary by 7 months of age and refined by 13 months (Kimmerle, Ferre, Kotwika, & Michel, 2010; Nelson, Campbell, & Michel, 2013). However, although there is a significant amount of studies addressing the developmental trajectory of uni- and bimanual movements and the symmetry/asymmetry of hand position at the beginning of the reach and during the

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http://dx.doi.org/10.1016/j.ridd.2014.05.023
0891-4222/

trajectory toward the object, there is limited information on how the two hands are coordinated at different stages of the reach (i.e., the beginning of the movement, object touching and grasping), especially at younger ages. In addition, very little is known about the performance of infants with developmental disorders.

Because the development of interlimb coordination reflects the maturation of cerebral areas and of perceptual-cognitive processes, understanding manual coordination when infants touch and grasp objects may reveal their ability to plan movements and to use sensory information to guide action. In this study, we will investigate the strategies used at the beginning of the reach, at object touching, and at the moment of grasping comparing typically-developing infants to infants with Down syndrome (DS). Besides motor delay (Tudella, Pereira, Basso, & Savelsbergh, 2011) individuals with this syndrome usually have altered cerebral organization, e.g., abnormal corpus callosum (Heath, Grierson, Binsted, & Elliott, 2007), reduced number of neurons at cortical layers II and IV (Wisniewski, 1990), and delayed post-natal myelination (Nadel, 2003) All of these can affect the organization of uni- and bimanual movements and the adjustments necessary to grasp objects with different properties.

Another goal of this study is to investigate the strategies used by infants toward objects with different sizes and the longitudinal changes in these strategies after reaching onset. It has been shown that the reaching skill and experience is determinant to the performance of these movements (Carvalho, Tudella, Caljouw, & Savelsbergh, 2008; de Campos, Costa, Savelsbergh, & Rocha, 2013). Therefore, the participants in this study will be matched by reaching onset instead of chronological age, in order to even the effect of reaching experience. Given that by the time of reaching onset and in the following month infants perform jerky movements that are not well tuned to object properties (Rocha, Silva, & Tudella, 2006b; Thelen et al., 1993), infants at those ages will be defined as *beginners*. About 2 months after reaching onset, reaches become smoother and straighter (Rocha, Silva, & Tudella, 2006a; Spencer, Vereijken, Diedrich, & Thelen, 2000), therefore this level will be defined as *intermediate*. About 3 months after reaching onset, infants become consistent at adjusting their movements to object properties, performing appropriate proximal and distal adjustments (de Toledo, de Almeida Soares, & Tudella, 2011; Fagard & Jacquet, 1996; Fagard & Pezé, 1992), therefore this level will be defined as *skilled*.

As infants with DS have slower interhemispheric connections (Heath et al., 2007), we hypothesize that at all the stages manual strategies in the DS group may be less adjusted to the object properties. In addition, because infants with DS may take longer to learn from experience (de Campos et al., 2013; Polastri & Barela, 2005) changes in uni- and bimanual strategies may be delayed in this group compared to typical infants.

2. Material and methods

2.1. Participants

Eight typically-developing infants (TD group) and seven infants with Down syndrome (trysomy-21; DS group) born full-term, with birth weight higher than 2500 g and Apgar index higher than 7 in the first and 10 in the fifth minutes were included in the study. All the participants in the DS group attended early intervention programs since 2 months of age and throughout the study period. The study was approved by the local Ethics Committee and the parents/guardians of all the participants signed an informed consent.

2.2. Procedures

Participants were longitudinally tested at 4, 5, 6, 7 and 8 months of age. As mentioned earlier, we defined as *beginner* level both the first assessment from 4 months onwards that the infant reached for the objects and the following month. For typically-developing infants, reaching started either at age 4 ($n = 7$) or 5 ($n = 1$) months; for infants with DS reaching started at age 4 ($n = 3$), 5 ($n = 2$) or 6 ($n = 2$) months. The assessment that happened 2 months after the first reach was defined as *intermediate* level. Assessments performed when the infants had been reaching for at least 3 months were defined as *skilled* level. The chronological ages that represent each stage for individual participants are shown in Table 1.

At each test, infants were positioned in a reclined chair with trunk support. Four spherical objects (Rocha et al., 2012) were used as stimuli: two large (12.5 cm in diameter) and two rigid (5 cm in diameter). The objects were presented at infants' midline, shoulders' height and arms' length. After each reaching movement, the object was presented again until seven trials were performed. Three cameras recorded the entire assessment. One was positioned above the testing area, and two were positioned on each side (Rocha et al., 2006a). The videos were watched afterwards by one examiner for coding of the variables described at Section 2.3. To test the reliability of the coder, a subset of images (three different infants, total of 180 reaches) was analyzed by two other experienced coders. The total inter-rater agreement for reaching variables reached 93.3%.

2.3. Data analysis

A reach was defined as the uninterrupted movement of one or the two arms toward the object that resulted in object touching (Rocha et al., 2006a). In some trials, object touching was followed by grasping, which was defined as fingers flexion and object enclosure (Toledo & Tudella, 2008).

Regarding interlimb coordination, reaches were categorized at the following stages: