Cognitive Development 37 (2016) 1–8

Contents lists available at ScienceDirect

Cognitive Development

Viewpoint matters: Exploring the involvement of reference frames in multiple object tracking from a developmental perspective

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ARTICLE INFO

Article history:
Received 28 July 2014
Received in revised form 13 October 2015
Accepted 17 October 2015
Available online 6 November 2015

Keywords:
Multiple object tracking
Grouping
Allocentric
Retinocentric
Global-local
Development

ABSTRACT

Earlier studies demonstrated that visual tracking of dynamic objects is supported by both scene-based and object-based reference frames, depending on the magnitude of scene displacement (Huff, Jahn, & Schwan, 2009; Liu et al., 2005). The current experiment tests if this pattern also applies to younger participants, i.e. school-age children, by comparing the effects of abrupt scene rotations on tracking performance of multiple dynamic objects in a 3D scene across five age groups (grade 1, 3, 5, 7 and adults). Scene rotations have two consequences: displacement of (1) the whole scene and, (2) individual objects. Tracking accuracy of 123 participants was measured across five age groups (grades 1, 3, 5, 7, and adults). Either 1 or 3 targets moved independently among a total of 8 identical objects for 5 s. The scene remained constant or was rotated by 10° or 20° after 3 s. Tracking performance of all participants was well above chance level (probability of 0.5) and an age-related increase in performance was observed. Contrasting the two factors revealed that scene rotation had a greater impact on performance than object displacement. Further, the effect of abrupt rotations was independent of age. These findings suggest that allocentric reference frames support attentive tracking across abrupt viewpoint changes and that scene-based tracking is already applied early in human development. Findings are discussed in light of new studies that link MOT to grouping processes (local and global). We propose that scene-based or allocentric processing abilities undergo a similar development as, or are connected to, grouping skills.

1. Introduction

The ability to keep track of multiple moving objects within a scene is critical to the successful negotiation of complex visual environments. For instance, crossing the street requires several attentional skills (Dunbar, Hill & Lewis, 2001; Tabibi & Pfeffer, 2007), but mainly to keep track of multiple moving objects. Although research has demonstrated a clear developmental trajectory in children's multiple object tracking with respect to the total number of objects that can be tracked, little is known

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http://dx.doi.org/10.1016/j.cogdev.2015.10.004
0885-2014/

about the mechanisms responsible for these changes. The goal of this paper is to better understand these mechanisms by exploring how children's tracking abilities are affected by reference frames and accordingly, global and local processing of several moving objects.

Attention allocation in complex dynamic environments is experimentally tested using the Multipe object tracking paradigm (MOT; Pylyshyn & Storm, 1988). While watching several identical moving objects, observers are asked to maintain focus on a pre-assigned group of target objects. Developmental studies demonstrated that the number of objects children can track simultaneously increases markedly between 3 years of age and adulthood (Dye & Bavelier, 2010; O'Hearn, Hoffman, & Landau, 2010; Trick, Audet, & Dales, 2003; Trick, Hollinsworth, & Brodeur, 2009; Trick, Jaspers-Fayer, & Sethi, 2005). However, the majority of studies has focused on children over the age of 5, except for O'Hearn et al. (2010) who tested typically developing 3- and 4-year-olds and people with Williams Syndrome on multiple object tracking (MOT) and memory for static spatial location. Less is known about which maturing system is contributing to or is responsible for the observed improvement. O'Hearn et al. (2010) suggest that the developing visuospatial working memory (see also Klingberg, 2006) or attentional resolution (Wolf & Pfeiffer, 2014) play a role, whereas others see the number of tracked objects as reflecting the limited capacity of the maturing attentional system (Alvarez & Franconeri, 2007; Trick et al., 2005). MOT studies involving young individuals with disorders (e.g. Autism Spectrum Disorders (ASD), Williams Syndrome, Fragile X, syndrome, and, Turner's syndrome) who typically showed a lower mean of successfully tracked objects (Farzin, Rivera, & Whitney, 2010; Beaton et al., 2010; O'Hearn, Landau, & Hoffman, 2005; O'Hearn et al., 2010; O'Hearn, Hoffman, & Landau, 2011) suggest that MOT may even be utilized as a screening tool to measure a developmental delay in different developing groups during childhood.

In addition to a developmental trend in tracking ability, tracking may change qualitatively with age and experience, for example referencing objects in relation to other objects and the presented scene. MOT tasks presenting objects in 3-D scenes enable the exploration of visuospatial attention during tracking, with regard to the question of whether reference frames are used during MOT tasks, and if so, which ones. Humans use reference frames to transform scattered visual information input into one stable and detailed representation. When constructing a reference frame, it is possible to use objects, the environment, or the viewer as reference points (Howard, 1982). At present, there is little agreement on the form of reference used during tracking. Liu et al. (2005) have speculated that MOT mechanisms in 3-D scenes only rely on allocentric, scene-based coordinates. Thus, referencing objects in relation to each other would make tracking robust against abrupt viewpoint changes—that is, the displacement of objects by cuts from one camera perspective to another should not influence tracking performance. To test this speculation, Huff et al. (2009) introduced scene rotations of 10°, 20°, and 30° to a MOT task that was adapted to 3-D. The authors hypothesized that allocentric representations are only necessary for a successful relocation of objects in cases of large viewpoint changes. Minor rotations, however, change retinocentric coordinates only minimally. Because tracking performance was significantly decreased in 20° and 30° conditions, but not for 10° rotations, they concluded that the visual system relies on the retinocentric framework and compensates for small displacements when tracking multiple moving objects. The authors attempted to test for the involvement of retinocentric processes by using the screen coordinates of objects and calculated their displacement in conditions with rotation. The extent of object displacement was analyzed for trials with 30° viewpoint changes and two targets, finding no effect between large and small displacement for targets far and close to the center of rotation, respectively. Thus, not the displacement of an object but the rotation of the whole scene determined tracking performance.

Scene-based processing presupposes the ability to integrate local sensory information into one global whole. The ability to reference objects in relation to each other, perceiving them globally as one dynamic structure, overcomes the capacity limitations of selective attention (Yantis, 1992) and makes tracking robust against abrupt viewpoint changes (Jahn, Papenmeier, Meyerhoff, & Huff, 2012). In MOT, this ability was discussed in light of the target grouping approach by Yantis (1992) who argues that tracking benefits from grouping the single targets into one higher-order object, such as three targets into a triangle. Recent studies by Evers et al. (2014) and Van der Hallen et al. (2015) modified a MOT task to explore grouping interference in normally developing children and children with ASD (autism spectrum disorder). Both research teams picked up the approach by Scholl, Pylyshyn and Feldman (2001), namely that target objects in MOT are units of attentional selection. They paired each target with a distractor by displaying a connecting line between them and compared the tracking performance to trials in which objects were left ungrouped. If the performance in the grouped condition was significantly worse than in the ungrouped condition, one can assume that global processing, which means that objects are perceived as connected to each other, interfered with the tracking task. And in fact, global processing in MOT was measured based on a weaker tracking performance in the grouped condition, supporting the idea that grouping may shape sensory processing throughout the whole life span (Carey & Xu, 2001). Another recent study by O'Hearn, Franconeri, Wright, Minshew, & Luna (2013) compared adults, children, and matched participants with autism on a modified MOT task. The multiple objects were grouped in two ways, first by arranging them (i.e. by varying the space between them), to imply a grouped element and second, by letting them move together. This design allowed the authors to compare performance, for example, on target–target and target-distractor trials. They found children aged 9–12 years to show the same influence of motion-based, as well as element-based grouping as adults. Processing of the scene rather than single objects may evolve to enhance tracking performance, for example, when target objects are perceived as connected. Scene-based, global processing has been observed in various studies using dynamic stimuli and different samples of clinical and typically developing children but it has not been explored whether this ability is under development (i.e. whether this ability partially explains the developmental curve of tracking performance in children).