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Toddlers' action prediction: Statistical learning of continuous action sequences

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ABSTRACT

The current eye-tracking study investigated whether toddlers use statistical information to make anticipatory eye movements while observing continuous action sequences. In two conditions, 19-month-old participants watched either a person performing an action sequence (Agent condition) or a self-propelled visual event sequence (Ghost condition). Both sequences featured a statistical structure in which certain action pairs occurred with deterministic transitional probabilities. Toddlers learned the transitional probabilities between the action steps of the deterministic action pairs and made predictive fixations to the location of the next action in the Agent condition but not in the Ghost condition. These findings suggest that young toddlers gain unique information from the statistical structure contained within action sequences and are able to successfully predict upcoming action steps based on this acquired knowledge. Furthermore, predictive gaze behavior was correlated with reproduction of sequential actions following exposure to statistical regularities. This study extends previous developmental work by showing that statistical learning can guide the emergence of anticipatory eye movements during observation of continuous action sequences.

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Introduction

Action sequences are continuous complex streams of movement. Underlying this intricate flow of information, actions contain statistical regularities that provide information about the structure of observed behavior. For instance, a typical experience for an infant might be observing a parent bake a pie by first gathering ingredients, preparing dough, mixing the filling, and placing it in the oven. This action sequence includes many movements with unique kinematics, a temporal structure, and contextual information. A complex challenge for infants is to efficiently process this diverse and continuous flow of motion, recognize and predict the substeps that define the overarching action, and reach an understanding of the overall goal of the behavior.

Recent developmental studies have demonstrated that action prediction—the ability to perform predictive gaze shifts during action observation—is mediated by infants' motor capabilities and their ability to associate actions with their effects (Falck-Ytter, Gredebäck, & von Hofsten, 2006; Hunnius & Bekkering, 2014; Jovanovic et al., 2007; Paulus et al., 2011; Reid et al., 2009; Stapel, Hunnius, van Elk, & Bekkering, 2010; Woodward & Sommerville, 2000). One outstanding question is whether statistical learning skills also support action prediction early in development. Statistical learning, defined as sensitivity to statistical regularities in the environment, has been shown to be a powerful learning tool that emerges early in development (Ruffman, Taumoepeau, & Perkins, 2012; Saffran, Aslin, & Newport, 1996). Infants' and toddlers' statistical learning skills were initially investigated in the auditory domain, and recently researchers have shown that statistical learning also allows infants to extract structure from visual input as well (Kirkham, Slemmer, & Johnson, 2002). The current study aimed to determine whether toddlers can discover the statistical regularities in action sequences and accurately predict upcoming actions and their effects during online observation.

Statistical learning: Sensitivity to sequential structure

The transitional probabilities that define the order of events in a sequence determine how predictable an upcoming event is relative to other possible events. Previous research has demonstrated that young infants and children are sensitive to probabilistic information in different sensory domains, including in the action domain (e.g., Amso & Davidow, 2012; Buchsbaum, Gopnik, Griffiths, & Shafto, 2011; Canfield & Haith, 1991; Wentworth, Haith, & Hood, 2002). These statistical learning paradigms typically feature a learning phase containing sequences with a consistent structure such that certain elements always occur in a predictable sequential order. Infants and toddlers subsequently demonstrate a novelty response by looking longer to test sequences that deviate from the structure observed during the learning phase (e.g., Baldwin, Baird, Saylor, & Clark, 2001; Saylor, Baldwin, Baird, & LaBounty, 2007).

For example, in a study by Baldwin and colleagues (2001), 10-month-olds were familiarized to videos of daily actions such as sweeping. During a subsequent test phase, they watched versions of these videos in which pauses were inserted in the midst of the actor's motion ("interrupting" videos) or at natural breakpoints in the action stream ("intact" videos). Infants increased visual attention to the interrupting videos, which was interpreted as evidence that they perceived a violation in the expected structure. Additional research has shown that, rather than being restricted to highly familiar events, infants can also learn the structure of novel abstract sequences (e.g., the dancing of a starfish) in which the only cues for segmentation are the transitional probabilities between dynamic events (Stahl, Romberg, Roseberry, Golinkoff, & Hirsh-Pasek, 2014).

Research on the role of statistical structure in action processing has until recently focused on segmentation abilities via reactive measures of learning. The current experiment investigated whether toddlers can anticipate upcoming actions or events during online learning of sequential actions using their statistical learning skills. Recently, Romberg and Saffran (2012) and Tummeltshammer and Kirkham (2013) demonstrated that infants can learn to make anticipatory fixations to the location where a visual shape will appear following an auditory or visual cue. Although this work suggests that infants can learn visual spatiotemporal relations and predict upcoming locations, it is unknown