Cognition 177 (2018) 226–233

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/cognit

Original Articles

Pointing perception is precise

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ARTICLE INFO

Keywords:
Pointing
Gaze
Perception
Joint attention
Hands

ABSTRACT

The spontaneity and ease with which we point understates the gesture's significance to understanding cognition. Onset of pointing in infancy predicts early word acquisition and signals a capacity for shared intentionality. Yet, notwithstanding its importance, there is little research on the perception of pointing and its referents. Here we show that perceptual acuity for discerning where another person is pointing is remarkably accurate. Thresholds, as low as 0.5° of visual angle across an interpersonal distance of ~2 m, are modulated by the referent's location in space and the hand used to point and remain constant when the pointer's eyes are occluded from view and when 'embodiment' cues are enhanced or minimized. Pointing with the index finger not only directs attention toward a general region of space but the morphology of arm, hand and finger can be used to discern the location of the pointer's attention with precision.

1. Introduction

Pointing – a gesture we primarily use to share attention with others (Cappuccio, Chu, & Kita, 2013) – involves extending the arm and index finger away from the body and toward an object or location of interest. The gesture has been described as 'a foundational building block of human communication' (Kita, 2003) as both the production and comprehension of pointing in infancy are crucial to language acquisition (Goldin-Meadow, 2007) and indicative of shared intentionality and a developing theory of mind (Baron-Cohen, 1997; Tomasello, Carpenter, & Liszkowski, 2007). Here we show that the perception of pointing, like the perception of eye gaze, is remarkably precise.

Unlike symbolic hand gestures (such as beckoning, 'thumbs up', or the peace sign) whose meaning is well-defined within a given culture, pointing with the index finger is a universal, deictic gesture whose purpose is to engage or redirect another's attention but whose referential meaning is ill-defined (Kita, 2003; Tomasello et al., 2007). In contrast to symbolic gestures, deictic gestures convey meaning not by the specifics of their form or movement but from the context in which they occur (McNeill, 1992). The problem of determining the referent of a pointing gesture is well studied in philosophy (Quine, 1960) and, even in simple acts of communication between adult and infant, establishing the gesture's referent may depend crucially on previous shared experience (Moll & Tomasello, 2007). Pointing serves to establish 'joint attention' between people so that they attend to the same location or object *and* are mutually aware of sharing this focus of attention (Baron-Cohen, 1997).

Numerous studies support this view that the primary function of pointing is to establish joint attention, at least by the later stages of infancy (Bertenthal, Boyer, & Harding, 2014; Butterworth, 2003; D'Entremont & Seamans, 2007; Tomasello et al., 2007) Indeed, pointing can serve to direct attention to a general region of space where language may intervene to specify an object or location more precisely. In an elegant study of dialog and gesture during a task in which adults were asked to indicate the location of a target object in an array to a partner, Bangerter (2004) showed that pointing largely supersedes verbal deixis for close-by arrays, whereas language use increases for more distal arrays. This complements reports that, from the age of ~2.5 years, children shift from using pointing alone, to pointing plus language to language alone when trying to unambiguously identify a referent for a partner (O'Neill & Topolovec, 2001).

However, little is known about the precision of this deictic cue in specifying an object within a zone of space. Given the cross-cultural nature of pointing (Kita, 2003), its universal onset in infancy (Butterworth, 2003) and its obvious role in early language development where it acts to single out specific locations or objects for the attention of others (Goldin-Meadow, 2007; Mumford & Kita, 2016), how precise is pointing and our perception of pointing?

Research on the perception of pointing is scant. Existing studies note a definite role for pointing in disambiguating two or more referents in peripheral space but suggest that both infants and adults are limited in their ability to use pointing to accurately localize targets (Butterworth & Itakura, 2000). With regard to infant perception of pointing, babies of 10–14 months are more likely to correctly locate the further of two

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https://doi.org/10.1016/j.cognition.2018.04.021
Received 19 November 2017; Received in revised form 20 April 2018; Accepted 24 April 2018
0010-0277/

targets in peripheral space when an adult points to the target than when they orient their head and eye gaze toward the target without an accompanying pointing gesture (Butterworth & Itakura, 2000). While infants can use cues from the adult's head and eyes to scan into the correct hemifield they often stop at the first target they encounter; pointing is needed for accurate spatial localization of peripheral targets. Butterworth and Itakura (2000) conducted a further test with young adults to examine whether pointing cues are understood by a process of vector extrapolation and found that acuity for target locatization varied between peripheral and central locations, lying between 4° and 10° of visual angle for peripheral targets and, rather surprisingly, requiring at least 15° separation for targets in central visual field. While these results show that pointing can improve spatial locatization of targets over head and gaze cues, they also suggest rather limited acuity with the authors concluding that the cues of head orientation, eye gaze direction and pointing with the index finger refer 'in an approximate way to zones of space' (Butterworth & Itakura, 2000).

In this study we ask observers to discern the direction in which a live model is pointing with the expectation that the perception of pointing, like the perception of gaze, should be quite precise.

This expectation is based on the many observations that gaze- and pointing-related behaviours are closely linked in human development (Carpenter, Nagell, & Tomasello, 1998). The ability to follow adult pointing gestures and adult gaze shifts emerges in early infancy (Bertenthal et al., 2014; D'Entremont, Hains, & Muir, 1997; Hood, Willen, & Driver, 1998; Scaife & Bruner, 1975), whereas pointing production and gaze checking emerge later (Matthews, Behne, Lieven, & Tomasello, 2012; Tomasello et al., 2007). Importantly, these behaviours are also functionally related in both language acquisition and in the development of social cognition (Brooks & Meltzoff, 2005; Meltzoff, 2007), and delays or anomalies in both gaze comprehension and in pointing are reported in autism spectrum disorders which are characterised by differences and difficulties in social cognition (Ashwin, Hietanen, & Baron-Cohen, 2015; Baron-Cohen, Allen, & Gillberg, 1991).

Perhaps this strong association between gaze- and pointing-related behaviours is not just a coincidence of developmental timing. For example, Cappuccio et al. (2013) argue that pointing might be conceptualized as 'an instrumental gesture' which has evolved to represent information on where we are looking and to signal the direction of our own gaze to others.

The study of gaze perception has a long history in vision research. Gibson and Pick (1963) were the first to use a live looker to measure people's ability to discern the direction of *dyadic gaze* – whether the looker is looking directly at the observer – and found that perceptual acuity was remarkably high, reflecting the limits of the visual system's spatial resolution. This finding has been replicated in both early studies (Anstis, Mayhew, & Morley, 1969; Cline, 1967) and by modern research using standardized psychophysical procedures (Jenkins & Langton, 2003; Moors, Verfaillie, Daems, Pomianowska, & Germeys, 2016). Symons, Lee, Cedrone, and Nishimura (2004) used a naturalistic live looker task to measure thresholds for *triadic gaze*, the acuity with which observers can discern the location or object to which another person is looking. Replicating results for dyadic gaze, they show that thresholds for detecting shifts in eye gaze are exceptionally low with a resolution of ~30 s arc when measured in terms of a discernible shift of the looker's iris or ~1.3° of visual angle when measured in terms of the gazed at objects. Thresholds increase and acuity drops for more peripheral targets and when the looker used one rather than both eyes (Symons et al., 2004).

This study uses a live pointer and psychometric procedures to investigate adult perception of index-finger pointing, with three main objectives; first, to examine visual acuity for triadic pointing comprehension via threshold estimation across visual field location, second, to compare acuity for left handed versus right handed points, and third, to examine the influence of eye gaze direction and embodiment cues on the estimation of where someone is pointing in space.

2. Material and methods

2.1. General considerations and analyses

Sample size, chosen in advance of data collection, is comparable to that used in research on gaze perception (Symons et al., 2004) and consistent with sampling in psychophysics where all observers are expected to show an effect (Anderson & Vingrys, 2001). Perceptual thresholds were analyzed in R (R Development Core Team, 2010) using ANOVA: Greenhouse-Geisser corrections were used when Mauchly's Test for Sphericity was significant and effect sizes are given by generalized eta squared (η_G^2) (Bakeman, 2005). Following Cumming (2014) point estimates and associated 95% confidence intervals are tabulated and plotted.

2.2. Experiment 1

2.2.1. Participants

Twenty student volunteers (10 female) with mean age = 27.10 years (SD = 10.43 years) participated. All had normal or corrected to normal vision with a hand laterality score of +0.51 s (SD = 0.43), range −0.50 to +0.90, on the McManus Brief Handedness Questionnaire. Two participants were left handed. The study was approved by the UCD Research Ethics Committee; in accordance with the Declaration of Helsinki all participants gave written, informed consent and were advised of their right to withdraw from the study at any time without prejudice.

2.2.2. Apparatus

Participants sat at a table of length 1820 mm, width 2130 mm and height 715 mm facing a purpose built wooden apparatus of length 1820 mm, width 60.5 mm and height 40 mm in which 91 cylindrical dowels of height 150 mm and diameter 20 mm were placed. Three groups of test dowels, 7 in centre (C) and 9 in both left space (LS) and right space (RS), were defined with respect to the participant's position as shown in Fig. 1. At each location, the central target dowel was marked by a coloured sticker clearly visible to the participant and all dowels were clearly numbered on the pointer's side.

In centre space the pointer pointed to 7 dowels that were positioned side by side (3 each to the immediate right and left of the central target dowel plus the target dowel itself) so that the centre-to-centre distance for a neighbouring pair of 'pointed to' dowels was 20 mm. In peripheral zones (LS and RS) the pointer pointed to 9 dowels (4 each to the right and left of the central target dowel plus the target dowel itself) but with pairs of 'pointed to' dowels now interspersed by an unused dowel so that the centre-to-centre distance for a neighbouring pair of 'pointed to' dowels was 40 mm. The spacing between the dowels that were pointed to was chosen to generate useable psychometric functions after piloting 3 participants, which showed coarser acuity in peripheral than in central space.

With their head positioned in a chin rest the participants' eyes were 1000 mm from the target dowel at C which subtended 1.15° of visual angle in width and 8.58° in height. For LS and RS, the distance between the participant's eyes and the target dowel was 1166.19 mm, and the participant's line of slight was no longer perpendicular to the stimulus plane. Visual angles were calculated accordingly. The visual angles separating the flanking dowels from the target dowel at C were ± 3.43°, ± 2.29° and ± 1.15° (see Panel B, Fig. 1) where negative and positive values indicate dowels to the left and right of the target dowel at 0°. In LS the corresponding values were −6.27°, −4.79°, −3.25°, −1.65°, 0°, +1.71°, +3.49°, +5.32°, +7.21°, and in RS they were −7.21°, −5.32°, −3.49°, −1.71°, 0°, +1.65°, +3.25°, +4.79°, +6.27° (see Panel C, Fig. 1).

The pointer was a female research assistant aged 21 years with normal, uncorrected vision and a laterality score of 1.0, indicating extreme right-handedness. She stood on the opposite side of the apparatus