Acta Psychologica 257 (2025) 105057

Contents lists available at ScienceDirect

Acta Psychologica

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

Perceiving social signals: The similarity of direct gazing and pointing

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ARTICLE INFO

Keywords:
Direct gaze
Area of direct gaze
Pointing gesture
Area of direct pointing

ABSTRACT

Gazing and pointing can have overlapping functions in social interaction. The perception of both social cues is remarkably precise. Nevertheless, the perception of direct gaze is characterized by an area of direct gaze rather than one single gaze direction. In fact, observers accept a range of gaze directions as direct. Here, we investigate whether there is an analogous area of direct pointing. Three experiments examine an area of direct pointing (about 5–9°) and compare it to the area of direct gaze. We find this area to be similar, but not equal, in shape and size. Furthermore, we examine the influence of different pointing gestures on the area of direct pointing. Results indicate a shift of the area of direct pointing dependent on the used limb (left or right). The results are discussed with respect to common underlying mechanisms of the perception of direct gaze and direct pointing.

1. Introduction

Gaze direction is an important feature in everyday communication and interaction (Kendon, 1967). The unique morphology of the human eye with its white sclera and dark pupil is especially helpful in successfully detecting other people's gaze direction (Kobayashi & Kohshima, 1997, 2001). The direction of gaze is most of the time also the direction of attention, and thus gives other people insights into a looker's intentions and future actions (Baron-Cohen, 1995). For joint and shared attention, it is often necessary to understand on which object the attention of the interaction partner is currently focused. Even newborns prefer to look at direct rather than averted gaze and furthermore, children at the age of three to six months are able to follow other people's gaze (D'Entremont et al., 1997; Farroni et al., 2002).

Like gazing, pointing can lead to joint and shared attention (Baron-Cohen, 1995). Moreover, the baby's gaze following of pointing gestures is learned shortly after it shows gaze following of the caregiver's gaze. It even seems that 10 to 14 months old infants were better in identifying targets further away with a pointing gesture than a looking gesture (Butterworth & Itakura, 2000). A pointing gesture often entails extending the arm, hand, and index finger in a straight line away from the body towards an object or location of interest (Cappuccio et al., 2013; Taylor & McCloskey, 1988). Unlike symbolic gestures (e.g., thumbs up), deictic gestures like pointing are perceived universally across cultures and redirect an observer's attention to an object, location or space of interest (Kita, 2003).

Both gazing and pointing are social cues, which are related to language acquisition and the development of social cognition (Brooks & Meltzoff, 2005; Meltzoff, 2007). As gazing and pointing are socially important gestures, it may not surprise that characteristics of the gazer or pointer such as example facial expressions (Lobmaier et al., 2008), or perceived social status (Dalmaso et al., 2012; see also Dalmaso et al., 2020 for an overview), additionally influence gesture perception. Gazing and pointing are both well developed in early infancy (Bertenthal et al., 2014; D'Entremont et al., 1997; Hood et al., 1998; Scaife & Bruner, 1975). Both are remarkably precise (Cooney et al., 2018; Gibson & Pick, 1963; Symons et al., 2004). It is possible to discriminate an iris shift as small as 30 s of arc or alternatively a target shift of 1.3° of visual angle. Thresholds of pointing gestures are even lower with 0.5° target shift. Both pointing and looking perception share a reduced accuracy in the periphery (Cooney et al., 2018; Lücking et al., 2015; Symons et al., 2004). In conclusion, pointing and gazing seem to share many phenomena and have similar functions in social interaction.

In the literature of pointing or gaze perception, two distinct tasks can be distinguished. Firstly, a triadic task, in which the observer must judge whether a third object is being pointed at or looked at by a pointer or looker. Secondly, a dyadic task, in which the observer must judge whether the pointer or looker is looking or pointing at the observer. In triadic tasks both gazing and pointing are perceived with some biases. While in gazing the horizontal, vertical and diagonal axis are overestimated in 2D (i.e. the gaze direction is judged to be more extreme; Horstmann, 2025; Anstis et al., 1969), the overestimation effect is

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https://doi.org/10.1016/j.actpsy.2025.105057
Received 13 December 2024; Received in revised form 29 April 2025; Accepted 30 April 2025
Available online 9 May 2025
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largely reduced, but not completely diminished, in 3D stimuli (Horstmann & Linke, 2025). In contrast, pointing perception in 2D often underlies a central tendency leading to vertical judgements are pulled towards a horizontal axis (Herbort & Kunde, 2016; Krause & Herbort, 2023). These findings were mostly reproduced in the horizontal dimension in 3D, although in some conditions the effect was flipped or diminished indicating an influence of the situation's spatial parameters (Krause & Herbort, 2024). One potential parameter is the observer perspective, which affects the judgements, as variance is higher for gestures seen from the side (Krause & Herbort, 2021, 2024). In contrast, in exocentric pointing tasks with rods serving as pointers, observers systematically overshot when they had to rotate the rod to be pointed at a target (Doumen et al., 2007), which is similar to the overestimation effect in gazing. To sum up, the perception of pointing and gazing is affected by systematic biases, although these biases may differ depending on context factors. Importantly, the main interest of the current study is not the perception of a pointing or looking gesture to a third object that both the looker/pointer and the observer can see, but to the observer himself. The topic of the current research therefore is direct gazing and direct pointing, that is, whether the observer perceives gazing or pointing to be directed at him rather than somewhere else. Whether and how the effects of a triadic task as explained above can be applied to a dyadic task (i.e. when the observer is the looked/pointed on object itself), as the perception of a direct gesture, is currently a matter of debate (for some results of the link between triadic and dyadic task in gazing see Linke & Horstmann, 2024a).

Our current study is concerned with the perception of direct gazing and direct pointing and their relation. While the term *direct gaze* is defined as the perception of being looked at (see Kleinke, 1986), no definition of the perception of a direct pointing gesture has hitherto been proposed. We shall define the corresponding category in pointing perception as direct pointing, which is the perception of being pointed at. The perception of direct gaze has been studied to some extent. The first study was by Gibson and Pick (1963) who asked observers to judge whether a looker (the stimulus) is looking at them using the method of constant stimuli. Gibson and Pick used a real looker who fixated on a scale directly above the observer in 10 cm increments from a distance of 2 m. For every gaze direction, the observers had to judge if they felt looked at (yes/no) by the looker. The results indicate that the perception of a direct gaze is narrowly tuned with a threshold of 3° (Gibson & Pick, 1963). This research was extended by Gamer and Hecht (2007) who introduced the gaze cone concept. They proposed that the area of direct gaze is cone-shaped with a stable angle over distance. They tested their assumption with multiple experiments showing a cone shaped area of direct gaze – the gaze cone – sized about 6–8°. The only exception was an experiment using a real looker rather than a computer avatar. In the experiment with the real looker, the gaze cone seems to decrease over distance. Horstmann and Linke (2021) extended the range of distances and found evidence consistent with the gaze cone concept for a photographed stimulus.

Research has also been conducted on the pointing cone, which, however, is defined differently in terms of content. The pointing cone does not deal with the perception of a direct pointing gesture but defines the distance properties of judging the target object of a pointing gesture (Lücking et al., 2015). It was shown that pointing does not indicate a single location and could therefore not be described as a ray extending the index finger and intersecting the target (e.g., Butterworth & Itakura, 2000; Lücking et al., 2015). Instead, Lücking et al. (2015) found the pointing gesture referring to an elliptical cone protruding from the finger so that several objects could be seen as potentially indicated. The closer an object is to the cone's central axis, the higher the probability that it is interpreted as being the target. Since the absolute area of the cone increases linearly with increasing distance, this approach displays the uncertainty that is related to pointing extrapolation to far distances. This theory may be transferable to gaze directions but by now, the pointing and gaze cone are defined quite differently. Therefore, in the following we talk about the area of direct gaze and the area of direct pointing to clearly distinguish between the measurement of direct gaze/direct pointing in contrast to the pointing cone approach by Lücking et al. (2015).

Although gazing and pointing share some common functions, the stimuli are very different. There are two approaches in explaining the perception of gaze direction as well as direct gaze. Firstly, the luminance approach proposes an estimation of gaze direction based on the luminance distribution of the eyes. First reported by Ando and Osaka (1998), the so-called bloodshot illusion shows a bias in perceived gaze direction when one side of the sclera is darkened. Ando (2002) concluded that the position of the dark iris can be detected by assessing the amount of visible sclera to the right and to the left of the iris. Direct gaze in a frontally seen face is seen as a special case of a highly salient luminance distribution which is symmetrical (Ando, 2002) and may be easier detectable than other luminance configurations.

Secondly, there is a geometrical approach stated by Anstis et al. (1969) to explain the perception of gaze direction and direct gaze. Anstis et al. found an overestimation of gaze direction (e.g., judging a gaze as more extremely rotated to the side than it actually is), and attributed this to the relation of the displacement of the pupil to the horizontally visible size of the eye. They assume that the eyeball appears smaller than it actually is, and that because of this misperception, the relative displacement of the pupil appears to be larger, resulting in an overestimation effect. The authors supported this reasoning by manipulating the visible "eye" size in an artificial eyeball (Anstis et al., 1969). More recently, the geometrical approach may also be known under the term iris eccentricity approach (see Otsuka & Clifford, 2018; Todorović, 2006; Todorović, 2009). The term "iris eccentricity" seems to be derived from its pendant of "retinal eccentricity". If one transfers this concept the gaze direction is derived by the calculation of the angle between the central axis and the pupillary/iris axis of the eye. Obviously, neither the central axis nor the pupillary axis is visible to the observer as it is positioned in the eye itself. Therefore, the lateral shift of the iris on the eyeball may be set in relation to the eyeball size (as it is visible to the observer through the horizontal eye opening; Horstmann & Linke, submitted) or alternatively the eyeball size itself may be used to estimate the central axis of the eye.

To our knowledge, there is no elaborate account of the perception of direct pointing in the literature so far. However, pointing interpretation can be described quite accurately by geometrical rules (e.g., Krause & Herbort, 2021). Thus, the iris eccentricity approach and pointing processing show some parallels on closer inspection. The extrapolation of the pupillary axis, which is then compared to the eyeball's central axis, corresponds to the "ray of gaze" in the real-world environment (under the negligence of vergence and fixation distance). Similarly, in pointing perception, the extended arm, including hand and index finger, is extrapolated towards potential referents (Herbort & Kunde, 2018). Nevertheless, there are some important differences between gaze and pointing estimation. Firstly, the pupillary axis is not visible to the observer, while the arm axis is. Secondly, the iris eccentricity approach essentially relates the decentering of the pupil to its center position (i.e., the pupil displacement in relation to the radius of the eyeball), whereas pointing interpretation is derived without any default comparison. Thirdly, the size of the eyeball is nearly fully visible to the observer, providing information on maximum rotation, unlike the pointing gesture, which offers a visible extrapolation axis but not the radiant of the rotation.

Both pointing and gazing can be used to detect rotation deviations. We would therefore expect similar results in detecting direct pointing gestures compared to detecting direct gaze. In contrast, there seems to be no equivalent approach in detecting direct a pointing gesture using a luminance-based perceptual mechanism. While the human eye has unique luminance features with its bright sclera and dark pupil (Kobayashi & Kohshima, 1997, 2001), a pointing gesture does not share these features. The contrast between arm/hand/finger and the body can differ due to different backgrounds and clothing, making it unreasonable to use these luminance features to determine the direction of a pointing gesture. In summary, depending on the respective theory about detecting gaze direction (geometrical vs. luminance), we expect similarities between pointing and gazing (geometrical approach) or differences in the perception of these cues (luminance approach). Given the similarities between the functions of gazing and pointing, it seems reasonable that the perception of a direct pointing gesture could follow similar rules as the perception of a direct gaze.

Only a few studies (see Butterworth & Itakura, 2000) have compared pointing and looking, but focusing on the rather distant topic of gaze or pointing following. These studies found similar effects of pointing and gazing but are of limited use in the present context, as they present extreme versions of pointing and gazing (maximum left vs. center vs. maximum right) rather than graded stimuli in a moderate range of directions.

In this study, we conducted three experiments to test whether there are similarities between the perception of direct pointing and direct looking (see Fig. 1 for an example illustration of similar area of direct pointing and direct looking). In the first experiment, we used a computer avatar and an artificial arm model to compare the area of direct pointing and the area of direct looking. In the second experiment, we extended this research by comparing the looking and pointing of a mannequin in a natural 3D environment. The third experiment examines the difference in the perception of direct pointing gestures by using several pointing gestures and a real person pointing.

2. Experiment 1

2.1. Method

2.1.1. Participants

Thirty-six observers (16 male, 19 female, 1 diverse), aged between 22 and 33 years, volunteered for course credit or candy. The sample size was chosen to detect small to medium sized differences between the pointing and gazing ($d = 0.45$) on the basis of a power analysis that yields a target-sample size, $n = 32$, for our critical hypothesis t-test with $1 - \beta = 0.8$ ($\alpha = 0.05$). All observers had normal or corrected visual acuity and intact color vision. They gave written informed consent before participation. This and the following experiments were approved by Bielefeld University's ethic committee, and are conformed with the Helsinki protocol (2008, extend).

2.1.2. Apparatus and stimuli

A computer-generated avatar as well as a hand model were presented on a 36.4 cm × 27.7 cm sized Sony Multiscan G420 monitor with a frame rate of 89 Hz. The display had a resolution of 1.280 * 1.024 pixels. The stimuli were presented in full-screen mode. The computer avatar's width of the head was 16.5 cm and its height was 25.8 cm. Its interpupillary distance was 6.5 cm, angle kappa of the eyes was fixed to 0°. The screen size of the virtual head approximately equaled that of an adult human head. The virtual head was generated based on a modified Sims (Die SimsTM 4, Electronic Arts GmbH) avatar, in which both eyes were cut out and replaced by transparent pixels. The simulated eyes were created and controlled by a customized Python script as simulated spheres. The relative sizes of eyeball, iris, and pupil were based on normative data as the average eyeball has a width about 24 mm, and the average iris is about 12 mm large (Gharaee et al., 2014; Sanchis-Gimeno et al., 2012). The simulated eyes are controlled independently in their horizontal rotation. Accordingly, it is possible to adjust the vergence angle between the eyes in addition to the nominal rotation angle. The avatar mask, with removed eyes, was laid over the simulated eyes. A rotation of 25° to the left as well as to the right was used as the widest eye rotation. Gaze can be adjusted in steps of 1°. In the following section, gaze to the left will be labelled as negative values. For this experiment, the vergence eye angle was fixed to the natural vergence at the presentation distance, which was 1.13° per eye for a distance of 165 cm. Please note that all measures are going to be described from the observer's perspective. A gaze 10° to the right is perceived out of the observer perspective, when the looker itself fixating 10° to the left out of its viewpoint (see Fig. 2).

The pointing stimulus was created by using an arm model including the forearm, the hand and the fingers. The arm model was fixed to a stand so that it could be positioned horizontally. By linking the indicated forearm to the fastening clamp of the stand, a lateral movement of a hypothetically complete forearm was approximately simulated, with the origin lying in the elbow joint. The length between the index fingertip and the center of rotation at the connection point of the clamp and stand was 42.4 cm. The index finger of the hand was outstretched, while the other fingers were clenched into a fist. The forearm and index finger were aligned. The arm model size was approximately equaled to that of

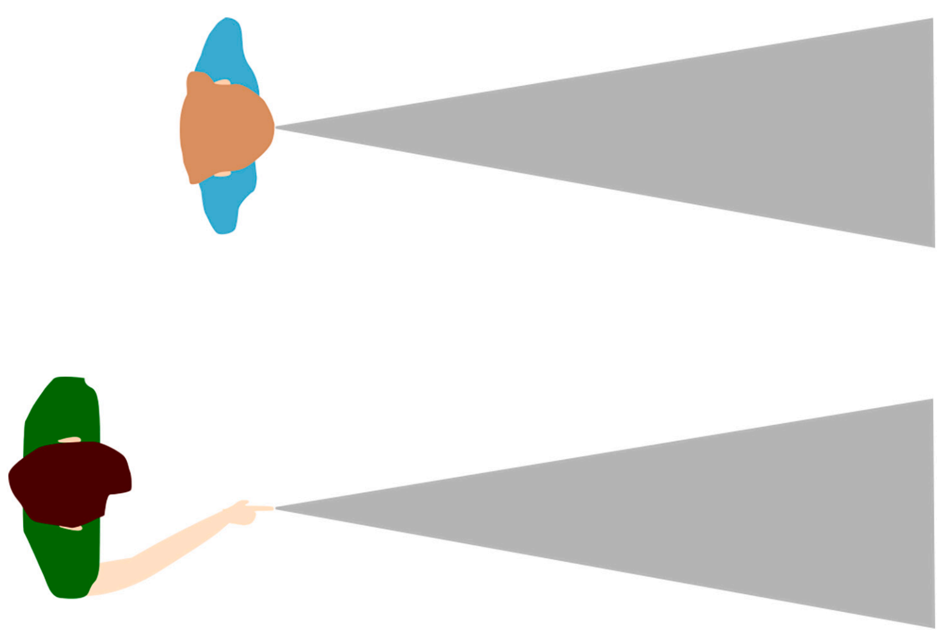

Fig. 1. Example of a possible cone-shaped area of direct gaze also called the gaze-cone (above) and cone-shaped area of direct pointing (below).

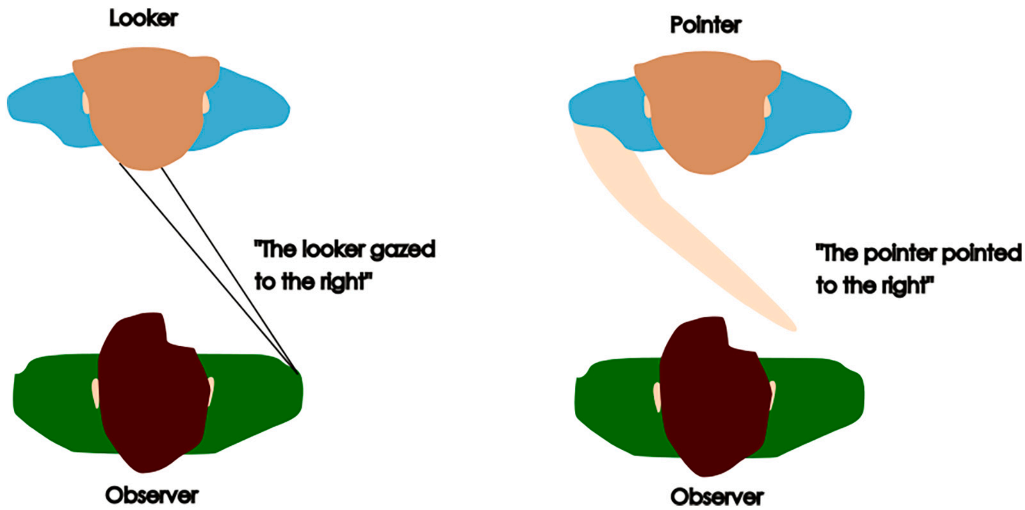

Fig. 2. Pictorial examples of the pointing and looking perspective. Distances are not to scale. All following gaze and pointing directions are given from the perspective of the observer.

an adult arm. The pointing gesture was modeled like a natural pointing gesture of a pointer's right hand (left out of the observer's perspective) with the outstretched index finger (see Fig. 3). Photos of the hand model were taken at a distance of 100 cm and with a vertical offset of 25 cm upwards. The stimuli were created by rotating the stand horizontally in steps of 1°. A maximum of 25° to the left and 25° to the right was realized. In the following section, pointing to the left will be labelled as negative values. As there are no previous studies describing the width of a possible area of direct pointing, we chose the range of pointing gestures to be about 50° to cover a wider range of possible sizes of the area of direct pointing.

Observers were placed in 165 or 200 cm distance from the computer screen (see Appendix A for a detailed view of the experiment setting). The minimal distance was chosen to diminish the possible influence of vergence (see Horstmann & Linke, 2021; Linke & Horstmann, 2022).

2.1.3. *Design and procedure*

Observers were either presented with a pointing cue or a looking cue. Distance (165 cm vs. 200 cm) and cue (pointing vs. looking) were presented blockwise in a random order. The series (ascending or descending) as well as the looking/pointing side (left vs. right) were randomly varied.

To measure the area of direct gaze or direct pointing, a method of adjustment was used. Similar to Horstmann and Linke (2021), participants should adjust the degree of rotation of the eyes or the forearm until they felt looked or pointed at or until they felt no longer looked or pointed at. We used ascending series and descending series. Ascending series started with an extreme horizontal rotation and could be adjusted in direction of straight gaze or straight pointing. Descending series started with straight gaze or straight pointing and could be adjusted to extreme horizontal rotation. For the right and the left side ascending and descending series were used to measure the width of the area of direct gaze or pointing.

For the right side, ascending series were combined with the instruction “just looked at” or “just pointed at”. At the start of the series, the eyes were rotated 25° or the arm was rotated 25° to the right. The participants then adjusted the rotation of the eyes or the arm in steps of 1° until that point where they perceived the gaze or pointing gesture as just directed at them. The maximum possible value – the reference point – was straight gaze or pointing (0° rotation). The second condition for right side series combined the instruction “no longer looked at” with descending series with eyes or pointing gesture starting at 0° rotation. Eyes could be adjusted in steps of 1° to 25° to the right and the arm could be adjusted in steps of 1° to 25° to the right. The same procedure was used for left side series, which was labelled with negative rotation values.

Presentation and response registration were controlled by a custom written Python script using routines from PsychoPy (Peirce, 2007). The instruction for a given trial was presented before each trial and was seen in a shortened version while performing the task. Using the scroll wheel of the mouse, eyes and arm could be adjusted. Scrolling upward shifted the gaze/pointing gesture to the left, while scrolling downward shifted it to the right. One scroll union of the mouse wheel corresponded to a shift of 1° in the displayed gestures. The observers could adjust the eyes or the

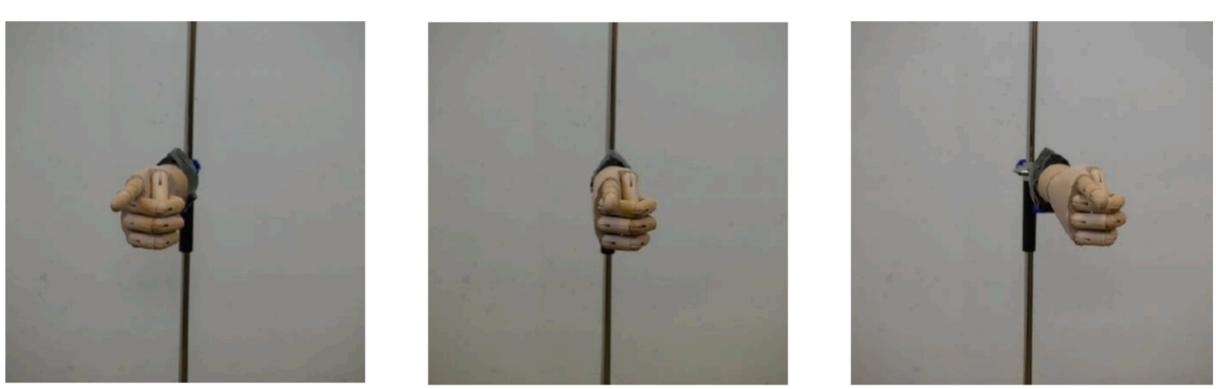

Fig. 3. Example of the shown hand stimuli in Experiment 1. Picture on the left shows a 10° rotation to the left, picture in the middle shows a 0° pointing gesture and picture to the right shows a 10° rotation to the right.

arm as long as they wanted to; they confirmed their final result by pressing the "enter" key on the keyboard. Two warm-up trials were made before the experiment proper, during which the researcher probed the participants' understanding of the task and provided answers to possible questions. Every condition combination was repeated ten times, resulting in 160 trials.

2.1.4. Transparency and openness

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study, and we follow *Journal Article Reporting Standards* (Kazak, 2018). All data, analysis code, and research materials are available at OSF (https://osf.io/cqndk/?view_only=bba578d4df844fe38a8d5f8b9b7869cc). Data were analyzed using R, version 4.2.1 (R Core Team, 2020). This study's design and its analysis were not pre-registered.

2.2. Results and discussion

The data of all 36 observers ($n = 36$) could be analyzed. The data were aggregated by observer, distance, cue, and side, which resulted in one mean per observer for all factor levels of stimulus side ("left" and "right"), series ("ascending" and "descending"), distance (165 vs. 200 cm), and cue (pointing vs. looking). The factor series was averaged to account for hysteresis and similar symmetric biases. Aggregated data were subjected to a repeated measures ANOVA with the variables side (left vs. right), distance (165 vs. 200 cm), and cue (pointing vs. looking). The ANOVA revealed a main effect for side, $F(1, 35) = 238.06$, $p < .01$, $\eta_g^2 = 0.85$, and a significant interaction between cue and side, $F(1, 35) = 9.60$, $p < .01$, $\eta_g^2 = 0.03$. A Bayesian *t*-test performed to confirm the non-significance of the cue effect revealed that it is 3 times more likely (for a distance of 165 cm: $BF_{01} = 3.2$, for a distance of 200 cm: $BF_{01} = 2.7$) that the area of a direct pointing gesture and direct gaze are equally sized than that they differ in size.

Since the left side of the direct gaze and pointing area was coded with negative values, the ANOVA provides insights into whether there is an area (rather than a ray) of direct gaze and pointing, rather than focusing on differences in the size between the left and right side of that area. To further investigate whether both sides are equally sized or if one side is larger, we conducted an additional *t*-test using absolute values (positive for both left and right sides). There was a significant effect of side with absolute values, indicating a larger area of direct gaze and pointing for the right than the left side, $t(35) = 7.24$, $p < .01$, $d = 0.37$.

The averaged threshold of the area of direct pointing was 5.56° (95 % confidence interval (CI) [5.45, 5.68]) while the averaged threshold of the area of direct gaze was 6.37° (95 % CI [6.24, 6.50]). The area of direct gaze was therefore slightly larger than for the arm cue, although this difference was not significant. There is a large significant correlation between the area of direct gaze and the area of direct pointing ($r = 0.80$, $t(34) = 7.73$, $p < .01$.) Both the area of direct gaze and the area of direct pointing do not differ between distances (5.99°, 95 % CI [5.86, 6.12] vs. 5.94°, 95 % CI [5.82, 6.07]). The threshold for the right side was significantly larger (6.43°, 95 % CI [6.30, 6.56]) than for the left side (5.51°, 95 % CI [5.39, 5.63]), for both factor levels of cue (arm and eyes; see Fig. 4).

The results of Experiment 1 indicate that the area for perceiving a direct pointing cue (10°) and a direct looking cue (12°) are similarly sized. This provides first time evidence for an area of direct pointing similar to the area of direct gaze. Furthermore, the area appears to have similar properties to the gaze cone. It remains stable over distance and can, therefore, be treated similarly to the gaze cone.

3. Experiment 2

Experiment 2 aimed to replicate the results of Experiment 1 with a different task and different stimuli. In Experiment 2, again a pointing and a looking gesture were compared. This time a mannequin in a physical (3D) environment was used. There are a multitude of differences between a photo and a 3D environment, which all relate to depth and perspective. A particular difference is the change of stimulus when

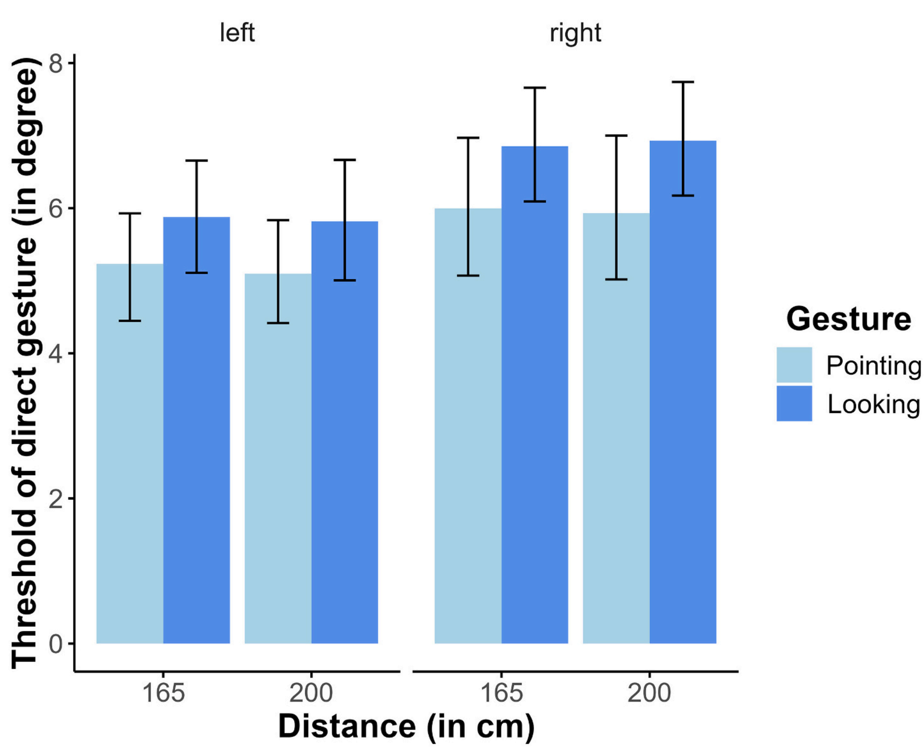

Fig. 4. Average threshold in degree of the area of direct pointing and direct gaze in the two tested distances (165 cm vs. 200 cm) in Experiment 1. The lighter blue indicates the averaage threshold of a pointing gesture, the darker blue of a looking gesture. Error bars describe the standard error of the average threshold in degree. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the observer changes position. As extensively discussed with respect to the famous Mona Lisa effect, there is no substantial change in the stimulus when the observer changes the vantage point in relation to a photo, but substantial change in relation to a 3D object (Todorović, 2006). In particular, aspects of the stimulus' 3D structure can be revealed by self-movement of the observer in a natural 3D environment. We might find larger differences between pointing and gazing in a natural 3D environment as the 3D layout of a hand and a head are markedly different. This is, the head is a spherical object, whereas the compound of finger, hand, and arm is an elongated object. The rotation of these object might be perceived similarly if a unified geometrical account is applied, where the perceived center displacement is compared to the perceived (or inferred) maximum possible displacement. Conversely, it is possible that they are perceived differently. For elongated objects, where the maximum possible frontal displacement cannot be directly observed, the elongation itself may be used to approximate the direction.

As we aimed in Experiment 2 to introduce 3D depth cues, the participants' task was to change their frontoparallel position. In particular, in the lateral displacement task (see Horstmann & Linke, in preparation), participants move to the side up to the threshold of being looked at. Similarly to the task of Gamer and Hecht (2007), this is a method of adjustment. If we recall the definition of the gaze cone, it is described as the area between looker and observer in which an observer perceives the looker's gaze to be directed at him. While Gamer and Hecht (2007) specify the task by adjusting the lookers' eyes, it is also possible to adjust the observer's position. Gamer and Hecht asked their observers to adjust the looker's eyes until they felt looked at or felt no longer looked at. Analogously, we asked our observers in Experiment 2 to move lateral until they felt looked/pointed at (starting at an edge position) or until they felt no longer looked/pointed at (starting at the central position), while the looker keeps his gaze or his pointing straight (see Fig. 5). Just as with gazing gestures, this task is also practical with pointing gestures.

3.1. Method

3.1.1. Participants

Twenty-five observers (m = 10, female = 15) aged between 19 and 53 years volunteered for course credit or sweets. All observers had normal or corrected-to-normal visual acuity and intact color vision. They gave written informed consent before participation. The sample size was chosen to detect medium sized differences between the two pointing and gazing (d = 0.55) on the basis of a power analysis that yields a target-sample size of n = 22, for our critical hypothesis t-test with a power of $1 - \beta = 0.8$ ($\alpha = 0.05$).

3.1.2. Apparatus and stimuli

The experiment was conducted in a large empty room without windows. A mannequin – the stimulus – was positioned at one end of the room. A straight gaze line originating from the mannequin was marked with fabric tape. Additionally, 200 cm and 400 cm in front of the mannequin, orthogonal lines were marked with tape (see Figs. 5 and 6). We used a mannequin (height: 190 cm) with normal human proportions to have better control about the stimulus. The arms of the mannequin could be freely moved and included joints at the shoulder, the elbow, the hand, and at the fingers (interphalangeal, metacarpophalangeal and carpometacarpal joints), see Fig. 6. The mannequin always pointed with its right arm being parallel to the floor, while the arm could be rotated horizontally. Additionally, the right index finger was also extended in line with the arm vector, while the remaining fingers were interlaced. The left arm and hand were adjusted downwards to the mannequin's side. The mannequin has a head that is similar in size to that of humans. The mannequin wore a wig with half-length hair and a middle parting, and had no facial features. Therefore, the looking direction of the mannequin had to be estimated only by the head direction. Depending on the condition, the mannequin was placed on the line's origin either with the head centered (looking gesture) or with the right index finger centered (pointing gesture). Note that therefore, in the pointing condition, the body midline of the mannequin was shifted to left side out of

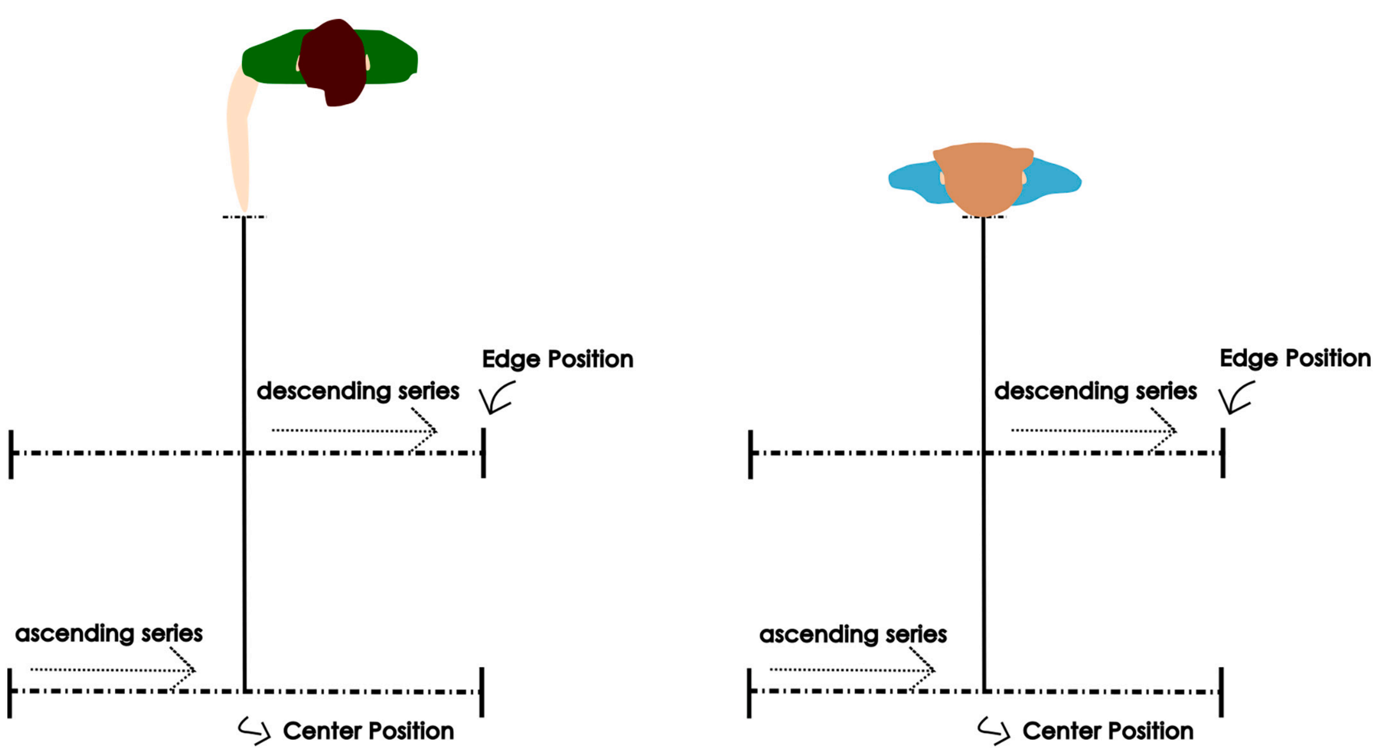

Fig. 5. Bird's eye view of the setup in Experiment 2. Dashed lines indicate the possible movement span of the observers. Dotted lines indicate the movement direction.

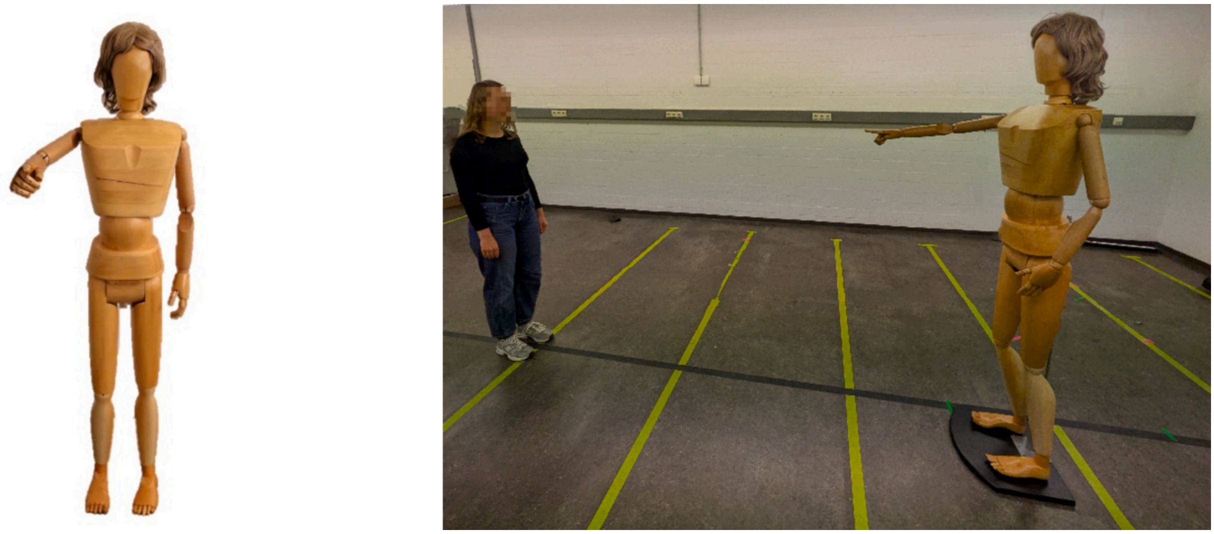

Fig. 6. Example picture of the mannequin. Left side shows the mannequin, right side shows an example from the setup of Experiment 2. The example depicts an observer at the center line at a distance of 2 m from the mannequin. The participant would move along the yellow lines to the side. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the mannequin's perspective, whereas in the looking condition the body the midline was centered. Both conditions resulted in the same distances between stimulus and observer. In the pointing condition, the head of the mannequin was covered by a grey piece of cardboard so that the head was not visible. Although, it was shown that eyes or head orientation only play a minor role in pointing perception and thus, the mannequin's head should hardly alter the pointing perception, we decided to cover the head to have only one visible cue per condition (Cooney et al., 2018; Herbort & Kunde, 2016; Krause & Herbort, 2023). In the looking condition, the pointing arm was lowered to hang straight by the side of the mannequin. The lateral displacement of the observer was measured with a flexible tape measure.

3.1.3. Procedure and design

At the beginning of each trial, the observer was directed to his starting position, which was either at the intersection between the straight gaze/pointing line and the orthogonal distance lines (center) for descending series or 200 cm to the right or left (edge) for ascending series (see Fig. 5). To obtain the boundaries of the area of direct gaze or direct pointing gesture, observers were instructed to move outward until they no longer felt looked at or pointed at (descending), or inwards until they just began to feel looked at or pointed at (ascending). To determine the central tendency observers were instructed to move inwards until they felt exactly looked at (ascending). When moving sideways in a crabwise manner, observers were instructed to maintain contact with the distance line markings and to keep their gaze on the mannequin as consistently as possible. Once they stopped and indicated that their position is final, the experimenter measured the lateral displacement relative to the center and noted the result (in cm) in the protocol. The reference point for the displacement was the position of the tip of the participant's nose.

The experiment included two blocks: the central and the border mode. In the central mode, the central tendency of the area of direct gaze/pointing was solely determined by ascending series (similar to Gamer & Hecht's [2007] centering task). In the border mode, the borders of the area of direct gaze/pointing were determined by using ascending and descending series to prevent hysteresis biases. Central mode was always presented before border mode. Within each mode, distance and gesture were blocked and randomly ordered. Within each blocked distance and gesture combination, ascending and descending series as well as the side were alternated randomly. In the central mode, a 2 (distance) × 2 (side) × 2 (gesture) design was conducted, where each factor level was repeated five times, resulting in 40 trials. In the border mode, the factor series was added resulting in a 2 (distance) × 2 (side) × 2 (gesture) × 2 (series) design, with a repetition factor of five, resulting in 80 trials. Thus, Experiment 2 consists of 120 trials in total.

3.2. Results and discussion

We will first present the classical analysis that we also conducted for Experiment 1. As we will see, the results indicate a change in analysis strategy that we will present afterwards as the Alternative Analysis.

3.2.1. Classical analysis

The data of central and border mode were analyzed separately. The central mode data were aggregated by observer, side, distance, and gesture. The data were subjected to a repeated measures ANOVA with the within variables side (“left” vs. “right”), distance (200 vs. 400 cm), and gesture (“looking” vs. “pointing”). The ANOVA revealed a main effect of side, $F(1,\ 24) = 24.00$, $p < .001$, $\eta_g^2 = 0.34$, a significant interaction between distance and side, $F(1, 24) = 19.94$, $p < .001$, $\eta_g^2 = 0.08$, and a significant interaction between side and gesture, $F(1, 24) = 8.91$, $p = .045$, $\eta_g^2 = 0.05$. The central tendency was shifted to the right resulting in a central tendency of -0.3° (95 % CI [-0.42, -0.18]) to the right for the left side, indicating that observers crossed the zero-degree line. For the right side, the central tendency was 1.24° (95 % CI [1.11, 1.37]) to the right. Central tendency for looking and pointing were not significantly different from each other and ranging from 0.46° (95 % CI [0.30, 0.62]; pointing) to 0.48° (95 % CI [0.35, 0.61]; looking) to the right. At 400 cm, the central tendency is slightly less shifted to the right compared to the 200 cm distance (0.41°, 95 % CI [0.30, 0.51] for 400 cm vs. 0.53°, 95 % CI [0.36, 0.70] for 200 cm).

In the border mode, the data were aggregated by observer, side, gesture and distance. The data were subjected to an ANOVA with the variables side (“left” vs. “right”), distance (200 vs. 400 cm), and gesture (“pointing” vs. “looking”) and revealed a main effect for side, $F(1, 24) = 20.21$, $p < .001$, $\eta_g^2 = 0.09$, distance, $F(1, 24) = 88.38$, $p < .001$, $\eta_g^2 = 0.52$, and gesture, $F(1,\ 24) = 47.32$, $p < .001$, $\eta_g^2 = 0.44$. There was a significant interaction of gesture and distance, $F(1,\ 24) = 12.34$, $p < .001$, $\eta_g^2 = 0.04$, and of distance and side, $F(1, 24) = 5.11$, $p = .03$, $\eta_g^2 = 0.01$. Observers moved farther to the right side than to the left side (46 vs. 40 cm/9.28° vs. 8.07°, 95 % CI [8.89, 9.68] vs. 95 % CI [7.68, 8.47]).

The effect of side was more pronounced in the pointing gesture condition (6.31° vs. 7.67°, 95 % CI [5.86, 6.76] vs. 95 % CI [7.22, 8.12]) than in the looking gesture condition (9.83° vs. 10.89°, 95 % CI [9.22, 10.40] vs. 95 % CI [10.3, 11.5]). Moreover, the larger the distance between looker and observer, the further the observer moved to the side (47 vs. 39 cm/10.69° vs. 6.67°, 95 % CI [10.20, 11.10] vs. 95 % CI [6.38, 6.95]). Gazing revealed a larger area of direct gesture perception than pointing (51.48 vs. 34.25 cm/10.36 vs. 6.99°, 95 % CI [9.93, 10.80] vs. 95 % CI [6.67, 7.31]). The direct gesture effect was more pronounced in near (12.77° vs. 8.60°, 95 % CI [12.10, 13.40] vs. 95 % CI [8.08, 9.12]) than in far distances (7.96° vs. 5.38°, 95 % CI [7.51, 8.41] vs. 95 % CI [5.06, 5.70], see Fig. 7). Nevertheless, the area of direct gaze and direct pointing significantly and highly correlate with each other ($r = 0.87$, $t(23) = 8.29$, $p < .01$).

3.2.2. *Alternative analysis*

As the distance effect in the classical analysis disagrees with the gaze cone assumptions, we rather analyzed the distance effect in cm by using a linear regression. First, we conducted a linear regression individually per observer, gesture and side with the lateral displacement as the dependent variable and the distance as the independent variable (see Fig. 8 for a visualization of the idea of the alternative analysis). Second, we extracted the intercept and slopes and conducted two repeated measures ANOVAs. The ANOVA with the intercept as the dependent variable and gesture and side as the independent variables revealed a significant main effect of gesture, $F(1,24) = 12.79$, $p = .002$, $\eta_g^2 = 0.26$, and side, $F(1,24) = 5.23$, $p = .031$, $\eta_g^2 = 0.04$, and no significant interaction. The average intercept is larger for a looking than a pointing gesture (36.38 vs. 23.46 cm, 95 % CI [29.90, 42.90] vs. 95 % CI [19.3, 27.6]), and larger for the right than for the left side (32.12 vs. 27.71 cm, 95 % CI [26.30, 38.00] vs. 95 % CI [22.10, 33.30]). The ANOVA with the slope as the dependent variable and gesture and side as the independent variables revealed neither significant effects nor interactions. The slope of the right and left side was equal (0.04 vs. 0.05, 95 % CI [0.023, 0.058] vs. 95 % CI [0.028, 0.064]). Slopes of looking and pointing were as well similar (0.05 vs. 0.04, 95 % CI [0.025, 0.047] vs. 95 % CI [0.028, 0.072]). We transformed the slope values from cm per unit to gain in degree. Therefore, the pointing gesture revealed a gain of the area of direct pointing of −2.00° on the left side and 2.12° on the right side. The looking gesture revealed a gain of the area of direct gaze of −2.64° on the left side and 3.13° on the right side (see Fig. 9).

Experiment 2 provides further evidence that the area of direct pointing is similarly shaped to the area of direct gaze. Furthermore, firstly a truncated cone can be observed as there is a range between the intercepts of left and right side regression line. This *intercept area* indicates that there is either no single point as the origin of the area of direct gaze/pointing or that the origin of the area of direct gaze/pointing is placed behind the stimulus (see Fig. 8). These two alternatives will be further discussed in the General Discussion. Moreover, again the area of direct pointing is clearly shifted to the right like in Experiment 1.

4. Experiment 3

Experiment 1 and 2 both showed an effect of side indicating that observers feel pointed-at at larger eccentricates when the looker is pointing to the observer's right side compared to pointing to his left side. Since the looker's right hand is on the observer's left side, the larger area of direct pointing of the right side of the observer is a contralateral extension. With a third experiment, we would like to investigate the effect of shown hand on the area of direct pointing. In contrast to the previous experiments, only pointing gestures will be presented. Instead of a computer avatar or a mannequin, a real person pointing is used who pointed either with his right arm, left arm, or with both arms.

4.1. *Method*

4.1.1. *Participants*

Thirty-two observers (13 male, 17 female) aged between 16 and 62

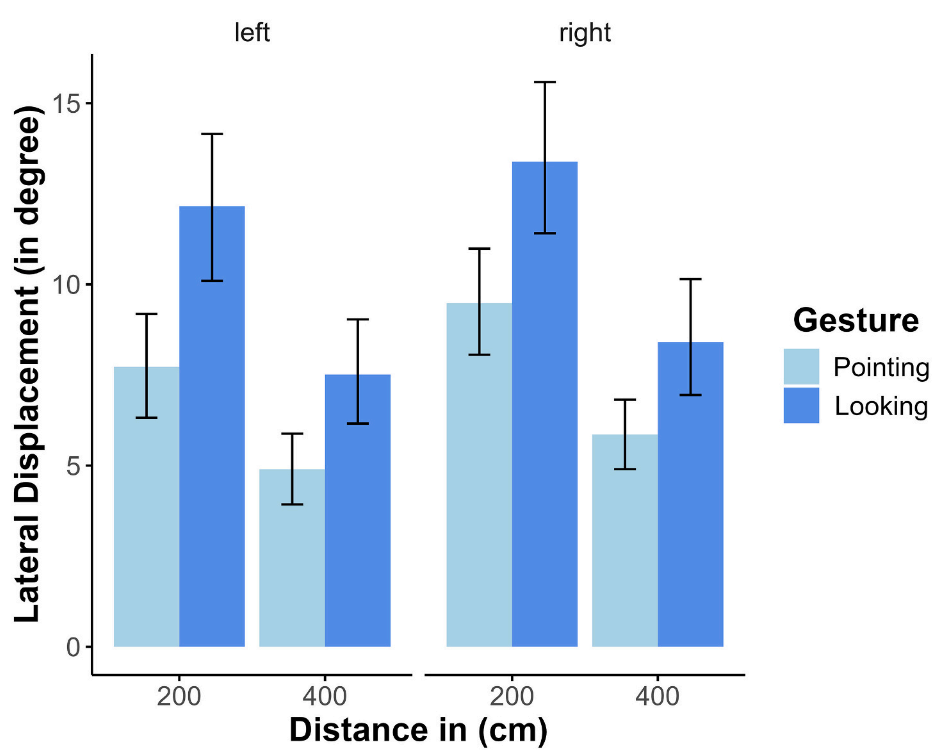

Fig. 7. Average threshold in degree of the area of direct pointing and direct gaze for the two tested sides (left vs. right) and the two tested distances (200 vs. 400 cm) in Experiment 2. The lighter blue indicates a pointing gesture, the darker blue a looking gesture. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

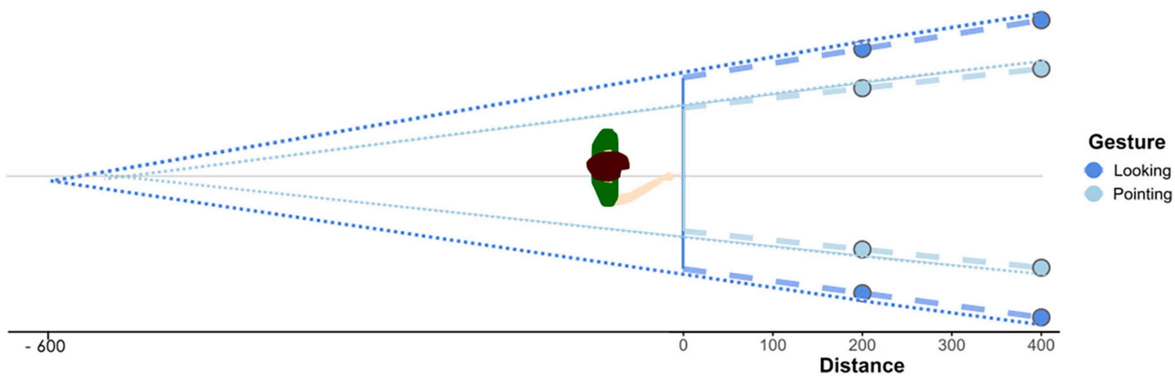

Fig. 8. Visualization of the idea of alternative analysis for Experiment 2 showing a a) cone origin point behind the stimulus, and b) an area of origin at stimulus distance.

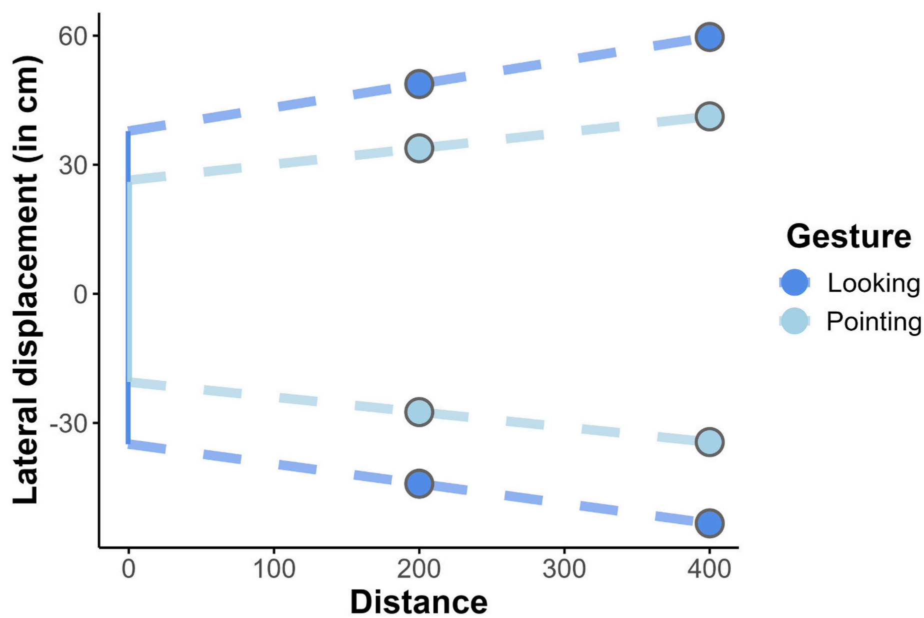

Fig. 9. Average threshold in centimeter of the area of direct pointing and direct gaze for the two tested sides (left vs. right) and the regression (dotted lines) per gesture in Experiment 2. Negative values indicate left side movements, positive values right side values. The lighter blue indicates a pointing gesture, the darker blue a looking gesture. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

years volunteered for course credit or candy. The age and gender information for two participants was not available. All observers had normal or corrected-to-normal visual acuity and intact color vision. All gave written informed consent before participating. The previous experiments found medium to large effects regarding the size of the left and right side of the area of direct gaze. A sample size of $n = 31$ was therefore chosen to be sufficient to detect medium to large effects (eta = 0.08) for our critical hypothesis one-way repeated measures ANOVA with $1 - \beta = 0.8$ ($\alpha = 0.05$).

4.1.2. Stimuli

The stimulus was a male live pointer with a height of 175 cm, a shoulder width of 47 cm, a shoulder height of 146 cm and an arm length of 74 cm. A stand with a platform was placed in front of the live pointer. It was centered to his body midline. The live pointer positioned either his left, right or both arms on a marked line of the platform indicating a 0° pointing gesture. The live pointer placed his straight arm on the platform and pointed with the respective index finger while the remaining fingers were interlaced. In the both-arms condition, the left and right hands' index fingers lied against each other while the remaining fingers of both hands were interlaced with each other. The distance between the body midline of the live pointer and the fingertip of his index finger was 59 cm. The eyes of the pointer were covered with mirrored sunglasses.

4.1.3. Apparatus, procedure and design

The apparatus and procedure were similar to Experiment 2. The same room as well as the same marked lines and distances were used. In contrast to Experiment 2, only the borders of the area of direct pointing were measured. Again, ascending and descending series were used to prevent hysteresis bias. The dependent variable was the displacement to the side, measured as the space between pole (positioned on the intersection between the straight pointing line and the varying distance lines) and the tip of the nose. A 2 (distance) × 2 (side) × 3 (pointing gesture) × 2 (series) design was chosen. The levels of the factor series were descending, that is from the center to the periphery, or ascending, that is from the periphery to the center. All factor combinations were repeated five times resulting in 118 trials per observer.

4.2. Results

4.2.1. Classical analysis

Data were aggregated by observer, side, distance and pointing gesture. The data were subjected to an ANOVA with the variables side ("left" vs. "right"), gesture ("right", "left", "both"), and distance (200 vs. 400 cm) and revealed a main effect for distance, $F(1,31) = 90.48$, $p < .001$, $\eta_g^2 = 0.64$, and gesture, $F(2, 62) = 6.91$, $p = .002$, $\eta_g^2 = 0.018$. There was a significant interaction of gesture, distance and side, $F(2, 62) = 16.58$, $p < .001$, $\eta_g^2 = 0.022$, and distance and side, $F(1, 31) = 10.87$, $p = .002$, $\eta_g^2 = 0.008$. The area of direct pointing was larger for the left and right arm condition (7.64°, 95 % CI [7.34, 7.95] and 7.69°, 95 % CI [7.39, 7.98]) than for the both-arms pointing condition (7.30°, 95 % CI [6.99, 7.59]). At 200 cm, the area of direct pointing was larger (9.30°, 95 % CI [9.02, 9.59]) than at 400 cm distance (5.78°, 95 % CI [5.61, 5.94]). While the right side of the area of direct pointing was larger in comparison to the left side (9.34° > 9.27°, 95 % CI [8.94, 9.74] > 95 % CI [8.87, 9.67]) for the short distance, this pattern reversed at 400 cm. Here, the right side of the area of direct pointing was smaller in comparison to the left side (5.57° < 5.98°, 95 % CI [5.33, 5.81] < 95 % CI [5.75, 6.21]). Although these differences were numerically small, they resulted in a significant interaction. The three-way interaction showed a contralateral larger side of direct gaze area depending on the pointing gesture shown for the far distance and an ipsilateral larger side of the direct pointing area for the near distance.

4.2.2. Alternative analysis

As the distance effect disagrees with an area, which is defined by a stable angle, we rather analyzed the distance effect in cm by using a linear regression. First, we conducted a linear regression individually for each combination of observer, pointing gesture and side with the lateral displacement as the dependent variable and distance as the independent variable. Second, we extracted the intercept and slopes and conducted two repeated measures ANOVAs on these two parameters of the linear regressions. The ANOVA with the intercept as the dependent variable and gesture and side as the independent variables revealed a significant main effect of side, $F(1,31) = 9.67$, $p = .004$, $\eta_g^2 = 0.06$, and a significant interaction of pointing gesture and side, $F(2,62) = 15.77$, $p < .001$, $\eta_g^2 = 0.16$. The average intercept is larger for the right than for the left side (27.57 cm vs. 24.19 cm, 95 % CI [24.0, 31.1] vs. 95 % CI [20.6, 27.8]) of the observer. The averaged area between left and right side intercept is thus 51 cm. The y-intercept shifted in direction of the shown pointing gesture (ipsilateral). Basically, the right arm condition was shifted to the right side (larger right side, smaller left side) and the left arm condition to the left side (larger left side, lower right side), whereas the both-arms condition was centered with a slight tendency to the right. While this tendency can be equally observed at the distance of 200 cm, quite the opposite picture is shown at the 400 cm data. Here, the left arm pointing gesture resulted in a larger pointing area on the right side, while right arm pointing gesture resulted in a larger pointing area on the left side (see Fig. 10). This turnover of the effect is also mirrored in the slopes:

The ANOVA with the slope as the dependent variable and gesture and side as the independent variables revealed a significant main effect of side, $F(1,32) = 28.30$, $p < .001$, $\eta_g^2 = 0.14$, and a significant interaction of pointing gesture and side, $F(2,62) = 32.60$, $p < .001$, $\eta_g^2 = 0.30$. The slope of the right side was smaller than that of the left side (0.03 cm vs. 0.04 cm, 95 % CI [0.022, 0.036] vs. 95 % CI [0.038, 0.051]). The slopes were larger for the contralateral pointing gesture (right arm and left side or left arm and right side).

Again, we transformed slope values from cm per unit to gain in degree. Thus, the left arm pointing gesture revealed a gain of the area of direct pointing of −2.08° (95 % CI [−2.53, −1.64]) on the left side and 2.83° (95 % CI [2.24, 3.42]) on the right side. The right arm pointing gesture revealed a gain of the area of direct pointing of −3.49° (95 % CI

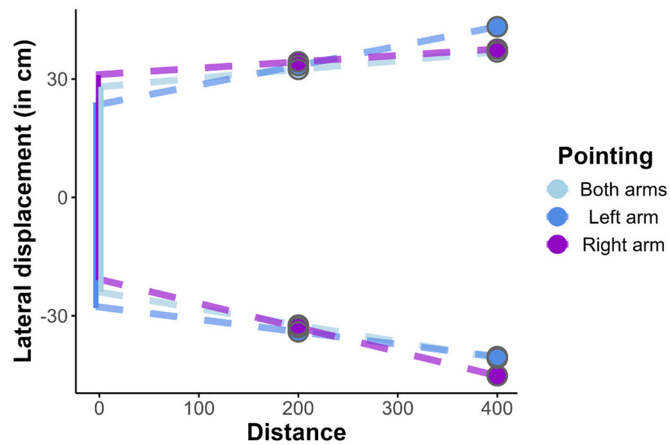

Fig. 10. Average threshold in centimeters of the area of direct pointing for the three tested gestures (left vs. right vs. both-arms) and the regression (dotted lines) per gesture in Experiment 3. Negative values indicate left side movements, positive values right side values. The lighter blue indicates a gesture with both arms, the darker blue a gesture with the left arm and purple a gesture with the right arm. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

[−4.14, −2.85]) on the left side and 1.40° (95 % CI [1.02, 1.78]) on the right side. Slopes indicated a larger gain for the contralateral side of the pointing gesture. Resulting in a larger area of direct pointing on the contralateral side at the larger distance (400 cm) than at the closer distance (200 cm) (see Fig. 9).

5. General discussion

In three experiments, we examined whether a direct pointing gesture is also perceived as indicating an area rather than a single spot and thus, resembles the perception of a direct gaze. Our experiments confirmed this hypothesis. The deduction of the rotation of gaze as well as of pointing seem to follow similar rules. Furthermore, both areas were relatively similar sized, independently whether observers only saw a 2D picture (Experiment 1) or a mannequin (Experiment 2) performing the direct gesture. Additionally, Experiment 3 confirmed the area of direct pointing with a real-life pointer for left, right, and both handed pointing. Firstly, we discuss the similarities between the perception of pointing and gazing. Secondly, we provide an overview about possible explanations for the change in shape from a perfect cone-shape in Experiment 1 to a truncated cone-shape in Experiments 2 and 3. Thirdly, we discuss the role of shared underlying mechanisms in pointing and gazing and fourthly, we dissect the influence of the shown hand of the pointer on the area of direct pointing.

5.1. Similarities between the perception of pointing and gazing

Firstly, we discuss the similarities between pointing and looking in detail. Experiment 1 showed a similar area for direct looking and direct pointing. The area of direct looking tended to be a little (but not significantly) larger than the area of direct pointing (6.3° vs. 5.5° respectively). Experiment 2 revealed a significant larger area of direct gaze than of direct pointing (10.36° vs. 6.99°). Both experiments showed a similar shape of the areas while the absolute size seems to differ. The difference in size may be explained by some unique features of the eyes in contrast to the pointing gesture. Firstly, in Experiment 1, our stimulus was a computer avatar with two eyes in human size. Although the gaze direction consists of two cues (left eye and right eye), the observer is told to just give one single judgment about the directness of gaze. The left and right eye are 6.5 cm away from each other, therefore, the exact direction for straight gaze for each eye should be shifted either to the right or to the left (see Linke & Horstmann, 2024b). This might complicate the process of judging the shown cue, inducing uncertainty and therefore widen the area of direct gazing (see Mareschal et al., 2014 for an overview) in contrast to the area of direct pointing. In the second experiment, the mannequin itself has no eyes but only facial features and the head direction to determine the gaze direction. Some studies have shown that in larger distances the cue of head direction is prominently used to judge gaze directions as the visual accuracy declines with distance and the eyes are barely visible to the observer (see the explanation about the repulsive effect in combination with distance variation given by Otsuka et al., 2014). Nevertheless, the absence of the eyes could also induce uncertainty and widen the area of direct gaze. The alternative analysis indeed showed only a difference of the intercept area (gaze > pointing) but no large differences between the gain, that is, the widening of the area when the distance is increased. The difference in uncertainty may therefore play a crucial role when judging both gestures. The pointing gesture with its relatively large visible rotation of the arm and index finger may therefore be easier to judge (see later discussion for an overview of tactics in perception of pointing gestures). Experiment 2 again provides evidence for a similar shape of both the looking area and the pointing area. Experiment 3 replicated the area of direct pointing with a real human pointer and different pointing gestures. The second and third experiments showed similar areas of direct pointing for intercept and slope suggesting a similar perception of pointing gesture for the mannequin as for the real-life pointer.

5.2. Truncated cone-shape

Interestingly, we could not find a cone-shaped area of direct looking/pointing in Experiments 2 and 3 in a real 3D environment when using the classical analysis. Similar to Gamer and Hecht (2007), the use of a real looker (or as in Experiment 2 a mannequin) changed the shaped form of a perfect cone with a stable visual angle (Horstmann & Linke, 2021) to a different shape with a shrinking visual angle when distance was increased. However, our alternative analysis revealed a different interpretation of the data: When we allowed the intercept to vary instead of forcing it on zero, the data are well in agreement with a cone shape as the measurements agree with a constant angle. Unless one assumes that the origin of the cone is behind the looker, the most reasonable interpretation of the results is one of a truncated cone with an area of origin rather than a point (see Fig. 11 for a visualization). The intercept area, defined as the area between the intersection of the left border with y-axis and the right border with the y-axis, was larger for the looking than for the pointing stimulus. There are several ways how this intercept area may be interpreted. First, the area reflects that in the near stimulus range the perception of a direct gesture is larger than originally thought by the cone metaphor. Since the perception of direct looking or pointing heavily depends on the spatial area in which an observer defines himself, it seems plausible that there are multiple positions where the observer accepts a gaze as direct. Imagine an average sized adult with a shoulder width of 40 cm as an observer who stands directly in front of the looker. It seems rather plausible that this adult would perceive all positions where his shoulder width intersects with the straight gaze (or for our mannequin, the straight head orientation) of the looker as being looked at in comparison to only one position where the exact middle of his chest intersects with the looker's gaze.

A second possibility, although somewhat unlikely in our view, is that the origin of the looker's gaze is behind the looker rather than at level of his eyes, or that the origin of the pointer's pointing gesture is behind the fingertip. While this might be found to be plausible for direct gazes as 2D stimulus on screen (Horstmann & Loth, 2019), there is no evidence to support this for a real human in real space for the looking cue (see

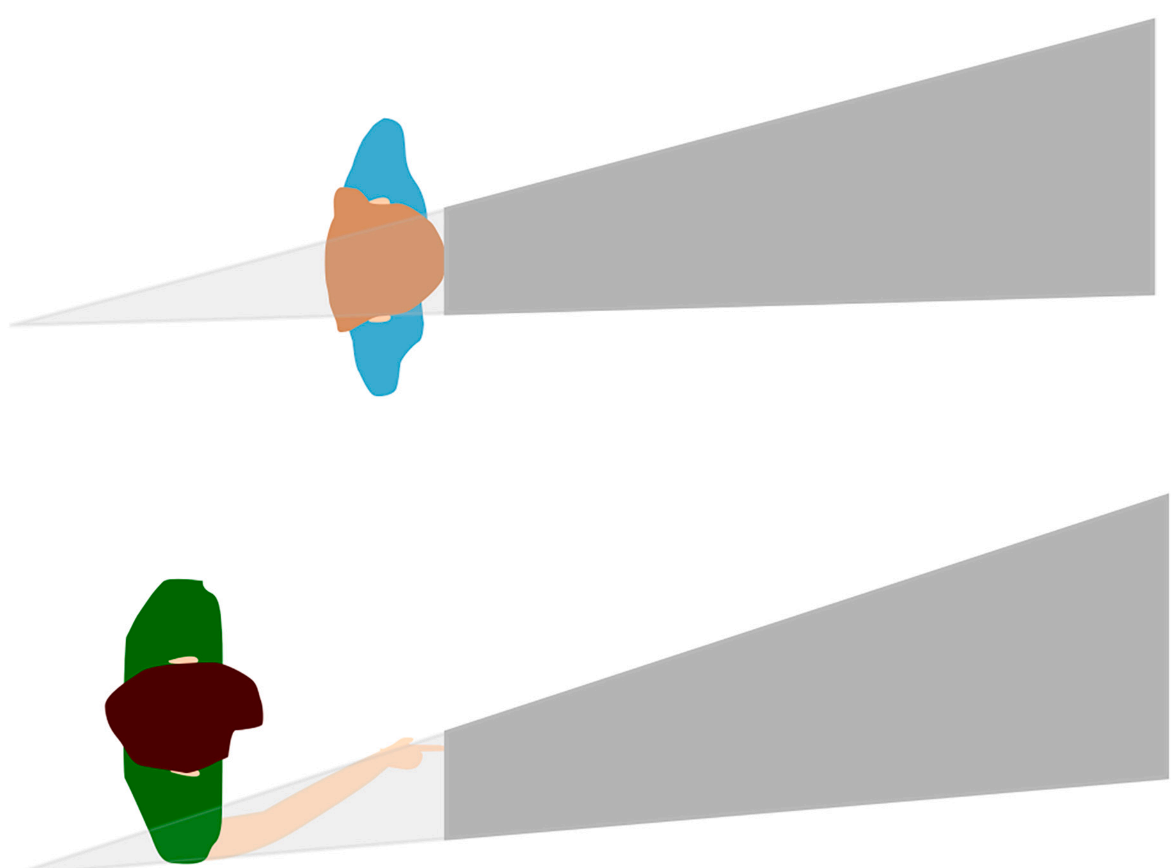

Fig. 11. Truncated cone-shape of the area of direct gaze and direct pointing gesture for the 3D environment experiments (Experiments 2 and 3) indicated by the results of the alternative analysis. Truncated cone is shifted contralateral to the gesture which is far more pronounced in the pointing condition.

Horstmann & Linke, 2025). For the pointing gesture, the origin may be at the shoulder joint rather than the fingertip. However, this is countered by the fact that the intersection of the left and right cone border of the pointing gesture is approximately 600 cm behind the fingertip, given that our mannequin has an arm length of 66.5 cm.

Investigating the origin of the gaze cone per se is beyond the scope of the present study. Nevertheless, we would like to clarify some assumptions of why the truncated cone could occur in the present experiments:

One could posit that the lateral displacement task is the sole cause of the alteration in the cone shape. While agreeing with the premise that the task itself may influence the threshold size of the area of direct looking and pointing (see Linke & Horstmann, 2024a), we would reject the hypothesis that the task changes the cone-shape independently on the change in presentation from 2D to 3D. The gaze cone is defined as the area between a looker and an observer, in which the observer perceives to be looked at (Gamer & Hecht, 2007). It is evident that both the lateral displacement task and the classical adjustment task (used by Gamer & Hecht, as well as in Experiment 1) would measure an area in space which meets the criterion for the gaze cone, as defined above. Secondly, and perhaps most significantly, with the classical adjustment task utilized by Gamer and Hecht (2007) there is also no evidence of a perfect cone shape with a real looker. Contrary to findings with a 2D stimulus, Experiment 4 of Gamer and Hecht (2007) utilized a real looker and used the classical adjustment task, but showed a clear distance effect, which mirrors a violation of the perfect cone assumption in a 3D environment. Nonetheless, the characteristics of the Lateral Displacement task have the potential to amplify the truncated shape as the observers move their own bodies in space, thereby potentially reinforcing the self-perception of their body width, which may influence the area of direct gaze and pointing as elucidated in the preceding section. Nevertheless, given the existence of a distance effect for a 3D stimulus in both the classical adjustment task and the lateral displacement task, we would not assume the task to be the primary cause of the truncated cone.

Another factor influencing the change in cone-shape may be the different distances between Experiment 1 and Experiment 2 and 3. However, the gaze cone concept has been demonstrated in a range of distances between 100 and 790 cm (see Gamer & Hecht, 2007; Horstmann & Linke, 2021) with no different characteristics in shape when using a 2D stimulus (see also Lobmaier et al., 2021, Balsdon & Clifford, 2018 and Harbort et al., 2013 for measurements between 57 and 100 cm, which are similar sized). For pointing there is no information for other distances ranges as there are no studies concerning the perception of an area of direct pointing. Nevertheless, as the change in shape occurs for both pointing and gazing with evidence for a "perfect" cone-shape in 2D stimuli for gazing in a range of distances including all distances used in Experiment 1 as well as Experiments 2 and 3, we would not predict the change in shape to be caused by different distances.

One other potential factor influencing the cone shape may have been stimuli characteristics that have changed between the experiments and consequently, might have changed the perception of direct gaze or direct pointing (more or less) independently on the change of the dimension from 2D to 3D. As our mannequin had no facial features, some well-known factors influencing the perception of direct gaze, such as facial expressions (see Dalmaso et al., 2020; see Lobmaier et al., 2008) could not be accounted in Experiment 2, in comparison to Experiment 1. One might imagine that facial expressions of anger for example widen the area of direct gaze as the gaze direction of an angry face may be more relevant for the observer (for example in terms of being cautious) than the gaze direction of a neutral face (see Lobmaier et al., 2008). Nevertheless, the significant change between Experiment 1 and 2 was not a change in size, but a change in shape of the area of direct gazing and pointing. There is no reason to assume that facial expressions can alter the area's shape. Moreover, in Experiment 2, the area of direct pointing was assessed with the mannequin's face covered to diminish effects of visible head rotation, thereby isolating the gesture's rotation. Furthermore, in Experiment 3, a real pointer was the pointing stimulus. In contrast to the mannequin, the real pointer had visible facial expressions, most of which could be seen by the observers except those features covered by the sunglasses. Nevertheless, Experiment 3 replicates the truncated cone shape of Experiment 2, despite the significant change in the availability of facial expressions to the observer.

However, we believe that the differences in area size between the looking and pointing gestures in Experiment 2 can be attributed to the absence of eyes or other facial features. This is because the only available cue for determining the gaze direction was the head orientation of the mannequin. Besides the facial contour, the facial features, such as the nose, are as important to judge the head rotation (see Langton et al., 2004) and its absence in Experiment 2 may induce additional uncertainty, potentially widening the area of direct gaze (see Mareschal et al., 2014). Furthermore, the eyes themselves were also absent, which would normally have a significant influence on the estimation of gaze direction (see Otsuka et al., 2014). The eye region is greatly influenced by facial expressions (Matsumoto et al., 2008), for example, the widening of the eye opening in the case of an angry face. This widening could indeed influence the perceived gaze direction (see Anstis et al., 1969). Therefore, an interplay between the perception of gaze direction and emotional expressions is quite possible. Nevertheless, in Experiments 1 and 3, the avatar as well as the real pointer had facial features. Our pointer was instructed to maintain a neutral facial expression, and our avatar also depicted a neutral facial expression. Therefore, we would explain the differences between our experiments to the variations in 2D and 3D presentation, rather than to the differences in the facial expressions of our stimuli.

5.3. Shared underlying mechanisms

In the following, we will discuss the results in relation to the luminance approach and the geometrical approach. Although we are well aware that our experiments cannot prove one or the other approach, they may contribute to the understanding of some shared mechanisms between pointing and looking gestures. In the literature on pointing, the predominant approach regarding the mechanism of pointing direction perception is the extrapolation of the shoulder and arm line (see Herbort & Kunde, 2018, and later discussion for details). In this approach, the rotation of the pointing gesture is derived by judging the ratio between shoulder joint and the hand. For the pointing gesture, this is clearly visible to the observer as the arm extends this rotation. This aligns with the geometrical approach in gaze perception literature. The key difference is that in pointing perception, the rotation itself is visible to the observer, while in gaze judgment, the rotation of the iris and pupil is estimated by their lateral displacement as an indicator for the foveal axis. Thus, the information of fovea placement as well as the rotation of the foveal axis is not directly accessible to the observer. Therefore, it is questioned whether the only available information – the rotation of the pupil on the eyeball, mainly visible as the displacement of the pupil in the eye – is actually used to judge the rotation, or if, as stated in the luminance approach, a completely different mechanism is employed. Out of our perspective, the presence of a roughly cone shaped area of direct gaze could be seen as some kind of evidence for a rotation judgment approach. The term "gaze cone" already describes the unique property that the area of direct gaze is characterized by a stable angle. The rotation judgment approach explicitly covers the constant angle over distance. Because a rotation angle per se is described by a pivoted ray and a ray itself has only a start point and extends to infinity, an elongation in space through distance is covered by any form of rotation approach. The luminance approach does not explain this phenomenon as the luminance distribution between iris and pupil would afford some additional mechanism to be extended or elongated with distance.

With the current experiments showing a cone shaped area for direct pointing gesture and for direct gaze and additionally, pointing perception clearly suggests a rotation approach, we would not assume that pointing and gaze perception rely on completely different mechanisms.

Otherwise, it seemed too much of a coincidence to find similar shaped and similar sized areas of direct gaze and direct pointing perception. Nevertheless, we do not explicitly test the difference between the luminance approach and the geometrical approach, so neither of the two approaches can be rejected or confirmed at this point.

5.4. *Influence of shown arm of the pointer*

Next, we would like to discuss the effect of the used arm (left or right) on the allocation of the area of a direct pointing gesture. In all three experiments, the area of direct pointing was shifted to the right (from the observer's perspective). For the first experiment, this implies an acceptance of more extreme rotations to the right than to the left. Likewise, for the second and third experiment, it implies a further movement to the right than to the left side. From the observer's perspective, the pointer pointed with the arm on the observer's left side (the pointer's right arm). Thus, the findings suggest a contralateral extension of the area of direct pointing. This is in line with a previous study in which Cooney et al. (2018) showed a considerable larger bias to the contralateral side in the perception of pointing gestures when pointer and observer facing each other and the pointed-at targets being between them. The authors suggest that contralateral points are harder to produce (later learned, slower, less accurate) and more relevant in our case that mechanically awkward points are harder to appraise by observers (Cooney et al., 2018).

Furthermore, pointing production and pointing interpretation do not follow the same rules (Herbort et al., 2020). In contrast to gazing where a fixation always hit the target, the indicated object of a pointing gesture is not so obviously accessible since the pointer's strategy is not considered by observers (Herbort et al., 2020). In natural situations, the pointer brings the hand/index fingertip in the line of sight to the target (Taylor & McCloskey, 1988). Therefore, when a pointer points straight ahead the pointing arm is a little horizontally rotated towards the body midline, which is the contralateral side to the pointing arm. Since observers base their interpretation on the extrapolation of the shoulder-fingertip line, a gesture that is actually intended by the pointer to point straight ahead is perceived by the observers as being directed slightly sideways (see Herbort & Kunde, 2016, 2018).

Especially our third experiment agrees with the shoulder-hand judgment rule of observers. As can be seen in the alternative analysis, the intercept (origin of the pointing gesture) is shifted in direction of the shoulder joint (ipsilateral to the shown hand), while the area of direct pointing is shifted in the contralateral direction – away from the shoulder joint to the opposite side. Nevertheless, observers seem to be biased from the shoulder-hand rotation angle but do not completely rely on it. If our observer would only consider the extrapolation of the arm/hand vector, we would expect a large bias similar in size of the rotation of the arm, which would be approximately about 21° for our pointer (pointer's shoulder width: 47 cm/23.5 cm from midline to each shoulder; distance from body midline to stand: 59 cm). However, our data in contrast reveals a significantly smaller horizontal displacement of 72.77 cm (from shoulder joint to measurement in 400 cm distance), which corresponds to a deviation of 10° as the largest possible direct pointing gesture. As we do not measure the central tendency of the pointer's different pointing gestures, we can only compare the objective arm-to-hand rotation of the pointer (21°) to the border of the direct pointing area, which is approximately 10° and therefore significantly smaller than the objective arm-to-hand rotation.

This considerably reduced bias is probably due to the fact that observers typically use two visual cues for interpreting pointing gestures. Not only the arm direction is relevant but instead also the fingertip position in the observer's visual field affects the interpretation. Since the performed gesture was almost at eye level and not too extremely rotated, it is reasonable to assume that it is placed near to the target like a mouse cursor on a screen (Krause & Herbort, 2021). At the same time, the direction of the shoulder-finger line was harder to derive and less weighted within the interpretation leading to a reduced contralateral bias.

To sum up, in all experiments we found evidence for an area of direct pointing. With an artificial hand model in a 2D space, with a mannequin in a real-life environment, and with a real-life looker, an area of direct pointing was evident. This area seems to be a little smaller than the area of direct gaze, which may rely on different features of the stimulus itself, but the shape is similar to the area of direct gaze suggesting a (truncated) cone-like shape.

CRediT authorship contribution statement

Linda Linke: Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Lisa-Marie Krause:** Writing – review & editing, Visualization, Formal analysis. **Gernot Horstmann:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was supported by DFG grant HO 3248/4-1 to Gernot Horstmann.

Declaration of competing interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Acknowledgements

Katrin Bosau, Igor Weimer, Vanessa Pape and Sezen Oban contributed to the conduction of the experiments. The experiments reported in this article were not formally preregistered. Data can be retrieved from OSF https://osf.io/cqndk/?view_only=bba578d4df844fe38a8d5f8b9b7869cc.

Appendix A

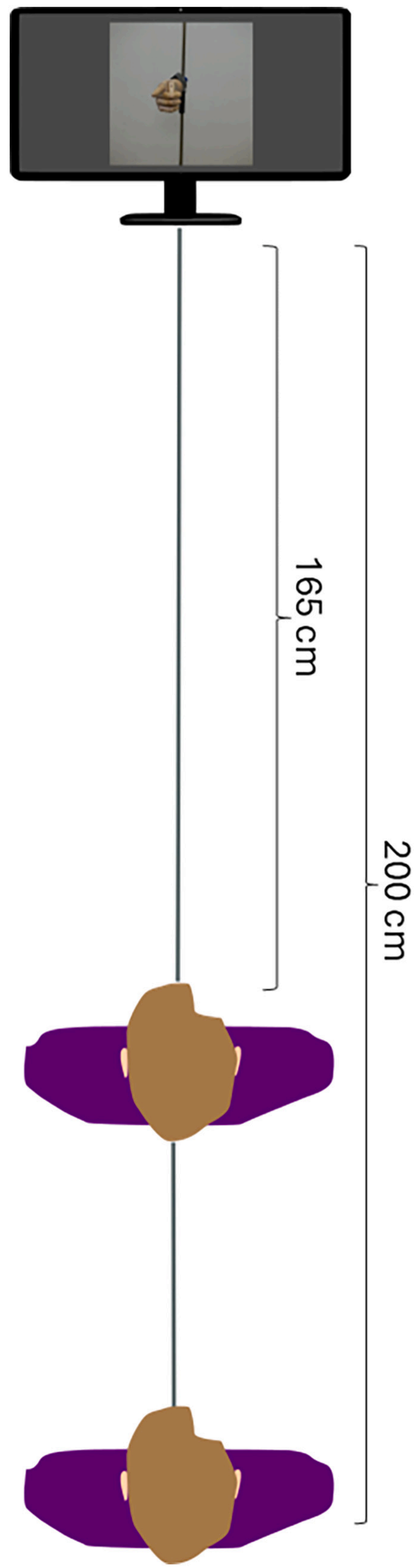

Fig. 12. Depiction of the experimental setting with approximately true-to-scale distances. Observers sit in either 165 cm or 200 cm distance from the screen.

Data availability

Data can be retrieved from OSF https://osf.io/cqndk/?view_only=bba578d4df844fe38a8d5f8b9b7869cc.

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