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Geometric Visual Illusion Effects on Visual Perception and Visuomotor Control: Emphasis on the Vertical-Horizontal Illusion

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GEOMETRIC VISUAL ILLUSION EFFECTS ON VISUAL PERCEPTION AND VISUOMOTOR CONTROL: EMPHASIS ON THE VERTICAL-HORIZONTAL ILLUSION

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LIST OF NOMENCLATURE

V-H Illusion—Vertical Horizontal Illusion

IT—Inverted T

MIT—Modified Inverted-T

H-staircase—Staircases With Horizontal Strips

V-staircase—Staircases With Vertical Strips

VF—Visual Field

2D—Two-dimensional

3D—Three-dimensional

V1—Primary Visual Cortex

V2—Secondary Visual Cortex/Prestriate Cortex

V3—Visual area V3

V4—Visual area V4

V5—Middle Temporal Visual Area

V6—Dorsomedial Area

CEM—Center-To-Edge Mode

ECM—Edge-To-Center Mode

ES—Effect Size

TF—Target Fixation

MF—Movement Fixation

RTF—Remembered Target Fixation

PV—Peak Velocity

COP—Center of Pressure

APA—Anticipatory Postural Adjustment

GRF—Ground Reaction Force

GRFampN—Amplitude of Normalized Ground Reaction Force

COPtime—Duration of center of pressure from onset to peak

COPamp—Amplitude of center of pressure from onset to peak

ABSTRACT

The focus of this dissertation was to explore the effects of potential vertical-horizontal (V-H) illusory influences on perceptuomotor control. As part of this focus we examined the potential use of separate cortical visual streams: the ventral visual stream for perception and dorsal visual stream for action. Three studies were conducted to determine effects of the V-H illusion influences on length estimations using upper limb point-to-point movements and lower limb stepping movements, involving various illusory configurations, movement directions, gaze directions. After a short introduction (Chapter 1) and a more detailed review of existing literature (Chapter 2), we present manuscripts on three studies. In the first study, we determined that manual length estimations of perpendicular segment lengths using curved point-to-point reaches corresponded to V-H illusory influences for movements, which began on the V-H illusion configurations rather than away from the illusion center. We concluded that encouraging gaze fixation on the center of the configuration likely contributed to the greater illusory influences over sensorimotor control. In the second study (Chapter 4), we directly assessed whether restricting gaze on the configuration or movement would alter V-H illusory influences on manual length estimations. Results revealed that restricting gaze on the configuration or movement space did alter general V-H illusory influences over sensorimotor control. We determine that the exploitation of V-H illusory cues can guide of upper limb movements given the specific gaze parameters. In Chapter 5 we assessed whether restricting gaze to the configuration or movement space also maintained V-H illusory effects on length estimations using stepping movements. Results demonstrated illusory influences, which did not exist for length estimations using movements of the lower limb with different gaze restrictions, did exist for movement planning and early movement execution. We concluded that exploitation of vertically presented V-H

illusory cues cannot guide completion of lower limb horizontal plane movements, even given specific gaze parameters. Taken together, these data provide evidence to support that given the right circumstances exploitation of simple deceptive cues can influence relative aspects of perceptuomotor control; however, people can utilize the separate pathways involving visual control for perception and action to produce manual length estimations which differ from perception.

CHAPTER 1. INTRODUCTION

Visual illusions provide an important role in visual perceptions (Gregory, 1991). Use of illusions contribute to the larger issue of examining how the central nervous system encodes and uses visual information for different cognitive and motor tasks (Mendoza, Hansen, Glazebrook, Keetch, & Elliott, 2005). Generally, illusions affect perceptions of object size and other spatial attributes such as orientation, position, speed, and displacement. Emphasis in this document is on visual perception of spatial variables, highlighting size and its influences on motor control, referred to as perceptuomotor control.

The ability to utilize perceptual influences to alter movement control is of interest because it has potential to influence rehabilitation efforts in people with motor declines. For example, the appropriate use of multiple vertical and horizontal segments on the rise and tread components of stairs, respectively, while stair climbing, revealed greater toe clearance than plain stairs (Foster, Whitaker, Scally, Buckley, & Elliott, 2015). These outcomes provide promise for illusory influences on perceptuomotor control in illuminated environments with eyes open. Because people cannot view the stair rise and tread simultaneously while stepping onto a stair, these results revealed that illusory influences exist in recent memory even with other allocentric cues available. Although they do not address whether illusory influences on perceptuomotor control remain for people allowed to continuously view illusions during movement, they do offer evidence for the potential use of illusory influences in rehabilitation.

Although cue-related properties, visual access, and type of task can influence movements, possibly of more interest is the comparison between the influence of visual illusions on perception compared to their influence on perceptuomotor control. Numerous researchers studied comparisons between the visual illusory influences on perception and action. On one hand,

results of some studies indicated that visual illusions do not bias body movements but influence individuals' perception accuracy. Evidence supports that the illusory effects on perceptuomotor control differ from those on perception, implying that geometric visual illusions influence human perception often exceed those for action (Aglioti, DeSouza, & Goodale, 1995; Ganel, Tanzer, & Goodale, 2008; Haffenden & Goodale, 1998; Haffenden, Schiff, & Goodale, 2001; Mon-Williams & Bull, 2000; Whitwell, Goodale, Merritt, & Enns, 2018) or can include no influence on movements such as grasping (Mack, Heuer, Villardi, & Chambers, 1985; Westwood, Heath, & Roy, 2000). Other researchers found similar illusory effects on perceptual judgments, visual adjustments, and movements. Effects of visual illusions on human perceptions of size were in accordance with effects on movement output (Daprati & Gentilucci, 1997; de Grave, Brenner, & Smeets, 2004; Elliott & Lee, 1995; Franz, 2001; Franz, Gegenfurtner, Bulthoff, & Fahle, 2000; Gentilucci, Chieffi, Deprati, Saetti, & Toni, 1996; Heath, Rival, & Neely, 2006; Meegan et al., 2004; Melmoth, Tibber, Grant, & Morgan, 2009; Predebon, 2004; van Donkelaar, 1999). Therefore, researchers hold divergent views on the association between perception and action.

In the vertical-horizontal (V-H) illusion with two identical length segments perpendicular to each other, people often perceive a longer vertical segment than a horizontal segment (Figure 1.1A) (Avery & Day, 1969; Finger & Spelt, 1947; Gavilán, Rivera, Guasch, Demestre, & García-Albea, 2017; Josev, Forte, & Nicholls, 2011; Kunnapas, 1957; Wolfe, Maloney, & Tam, 2005). Numerous studies involving this illusion have included illusory effects on perceptions, by adopting various V-H illusory configurations (Figure 1.1A, 1.1B and 1.1C), investigation methods (size judgment and

metric length estimation), orientations (rotating the configurations at various angles), sizes, viewing conditions (binocular and monocular), gaze strategies (fixed and free gaze), and use of different populations (e.g. healthy subjects, patients with left hemi-neglect, and patients with right brain damage). In most studies, stronger V-H illusions accompany symmetrical bisected configurations (inverted T - IT) (Figure 1.1A) (Avery & Day, 1969; Finger & Spelt, 1947; Gavilán et al., 2017; Josev et al., 2011; Kunnapas, 1957; Wolfe et al., 2005), 180°-rotated configurations (Chouinard, Peel, & Landry, 2017; Kunnapas, 1955a), smaller size configurations (Thompson & Schiffman, 1974), female performers (Fraisse & Vautrey, 1956), binocular vision (Prinzmetal & Gettleman, 1993), and central fixation (Chouinard et al., 2017) compared to their counterparts (see examples of unsymmetrical configurations: modified inverted-T - MIT, Figure 1.1B and L, Figure 1.1C). Moreover, patients with left hemi-neglect and/or right brain damage were more influenced by V-H illusions than healthy participants (de Montalembert & Mamassian, 2010).

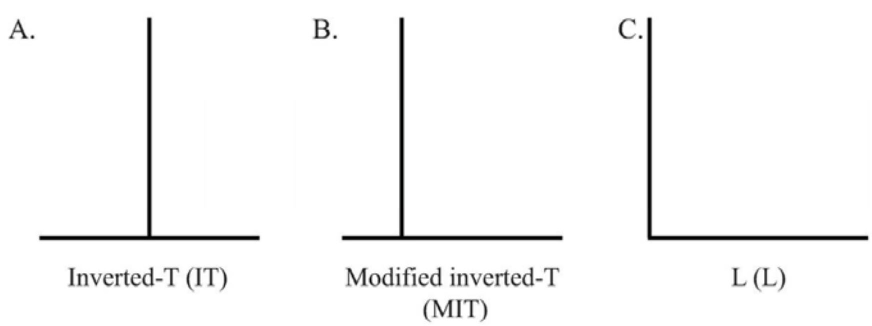

Figure 1.1. Different configurations of the V-H illusion: inverted T, IT (A), modified inverted T, MIT (B), and L (C). Horizontal and vertical segments for each stimulus are equal in length, yet the vertical segment appears longer to many people, especially for IT.

Few studies involve V-H illusory influences over movement. The two opposing views regarding to influences of visual illusions on perception and action remain for this illusion. The V-H illusion has affected perceptual judgments and movements similarly (Elliott, Vale,

Whitaker, & Buckley, 2009; Foster, Buckley, Whitaker, & Elliott, 2016; Foster, Whitaker, Scally, Buckley, & Elliott, 2015; Vishton, Rea, Cutting, & Nunez, 1999) and differently (Servos, Carnahan, & Fedwick, 2000; Vishton et al., 1999). The V-H illusory influences over open-loop tasks did exist for several experiments. In these open-loop tasks, people received visual feedback before (Vishton et al., 1999) or before and during the early phase of their movements only (Elliott et al., 2009; Foster et al., 2016; Foster et al., 2015), rather than vision during the whole movement. In one experiment subjects closed their eyes before making a grip aperture adjustment, and although they succumbed to the V-H illusion, the illusory influences were greatly attenuated to suggest an influence of allocentric cues (i.e., visual feedback of the environment) when moving toward a remembered triangle and a square (Figure 1.2). Results of two experiments within one study suggest that open-loop pantomime movements with remembered-targets (eye closure during movement execution) could be influenced by the V-H illusion (Vishton et al., 1999). Illusory vertical magnitude/horizontal magnitude of the triangle was also perceived as greater than that of the square to suggest similar influences on perception and action for this configuration (Vishton et al., 1999). In this instance motor grasping tasks aligned with perception when people receive no visual or tactile feedback of the illusory object during the movement of a pantomimed grasp (i.e., a grasp to estimate the length of the horizontal segment). In contrast, the illusory influences did not always exist, especially for closed-loop tasks. The use of a closed-loop task in which participants received complete visual feedback before and during actual grasping of the horizontal segment of an IT (Servos et al., 2000) and open-loop pantomime task in which people separated the thumb and index finger as if picking up a vertical segment in the V-H

illusion (Vishton et al., 1999) did not always succumb to the V-H illusion to the same extent as perceptual judgments. Without continuous visual feedback of an open-loop pantomime reaching task, the illusion was much weaker in this reaching task than that in the perceptual task (Vishton et al., 1999). The lack or reduction of V-H illusory influences over a closed-loop control task (Servos et al., 2000), suggests that use of updated visual inputs can eliminate or partially eliminate illusory influences over movement. Additional experiments on this topic are needed to provide support for this evidence.

A

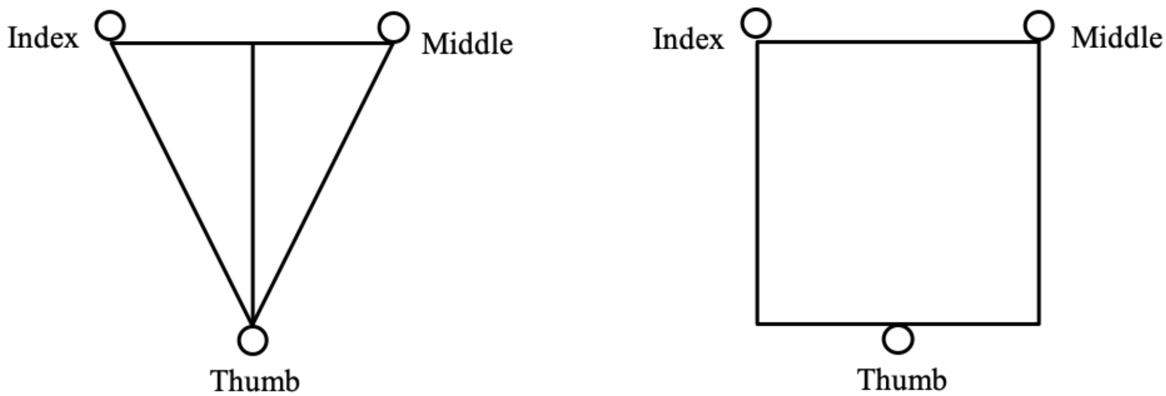

Figure 1.2. Examples of figure approximating the printed vertical-horizontal illusion (Vishton et al., 1999). Participants viewed the printed triangle (A) and square (B) and reached for them as if to grasp a thin object with three fingers. Circles represent the expected location for middle finger, index finger, and thumb, respectively. Note, the same positioning for each finger.

As described above, previous research revealed both similar and different visual illusory influences on perceptions and actions. Some researchers blamed variations in methodologies for the different outcomes (Bruno, Bernardis, & Gentilucci, 2008). One potential methodological difference across studies that may explain outcome differences involves the use of gaze direction. While tracking the eyes during a visual perception experiment, researchers found that fixation on the visual illusion produced stronger illusory judgments than free gaze (Chouinard et

al., 2017). Although these results were limited to perceptual outcomes, they may explain differences in motor performances.

Research involving variations of the V-H illusion during lower limb movements revealed illusory influences for perceptual judgments and step control. In a single staircase study, researchers modified 3D V-H illusion and applied it to a staircase in two different presentations (Elliott et al., 2009). In the first presentation (V-staircase), several vertical stripes were presented on the staircase riser, which was parallel to the frontal plane of the body, and horizontal stripes were on the tread surface of the staircase on the horizontal plane. The horizontal stripes and vertical stripes switched in the second presentation (H-staircase). Individuals asked to judge the height of a staircase orally perceived staircase height in V-staircase was greater than that in H-staircase. These perceptual outcomes corresponded with their stepping results. Individuals showed greater vertical toe clearance of the lead-limb when stepping on the V-staircase than the H-staircase. Two other studies further confirmed the effects of the V-H illusion on foot toe clearance when stepping on more than one staircase and crossing a low-height obstacle (3, 5, or 7 cm). Individuals lifted the lead foot higher when the vertical stripes were placed on the front riser of a staircase (Foster et al., 2015) or surface of the obstacle (Foster et al., 2016). Thus, in these open-loop tasks, lower limb movements were influenced in the direction of the modified V-H illusion.

In this document, we designed a series of projects to determine the effects of illusory-like and illusory configurations on perceptual judgments and perceptuomotor control. Illusory inflences were based on the V-H illusion, while perceptuomotor tasks involved either manual or step estimations of one segment length of illusory-like or illusory configurations.

Text in **Chapter 1** provides an overview of this dissertation and background information to motivate three experiments. Review of the existing literature in **Chapter 2** provides information on several visual illusions with greater detail on the vertical-horizontal illusion and evidence of various outcomes of effects of the vertical-horizontal illusions on individuals' visual perception and motor control.

The first study in **Chapter** 3 was designed to determine the effects of illusory-like configurations on perceptuomotor control. We examined the potentially deceptive influences of the vertical-horizontal (V-H) illusion on manual length estimations made toward or away from the V-H configuration intersection. Results revealed that manual length estimations differed between upright and rotated orientations and followed common V-H illusory perceptions when moving away from configuration intersections to support that exploitation of deceptive two-dimensional visual cues can direct general upper limb control for sensorimotor coordination. Other results revealed that manual length estimations opposed those of expected perceptual responses to support a control separation between perception and action for manual length estimations.

In **Chapter 4**, we examined whether potentially deceptive influences of the IT V-H illusion on manual length estimations varied by gaze directions. Participants directed their gaze freely, on the configuration, or on the movement. Participants used downward or rightward pointing movements to manually estimate the length of a short bisecting segment of the V-H illusion in upright or rotated configurations. Manual length estimations for upright and rotated configurations depended on gaze direction, revealing bisection influences only for restricted viewing. People produced illusory influences on perceptuomotor control only when gaze was directed toward V-H configurations or their movement. These results show evidence that

exploitation of deceptive visual cues can direct upper limb control for sensorimotor coordination. The few significant correlations between length estimations and perceptual responses again revealed a control separation between perception and action for manual length estimations.

In **Chapter 5**, we examined whether potentially deceptive influences of the IT V-H illusion on step length estimations varied by gaze directions. The primary goal was to determine whether length estimation using a step movement on the ground was influenced by vertical presentation of the V-H illusion when forcing gaze directions during such movement performance. Participants looked at the center area, remembered center area of IT, or the movement while making estimations during a forward step execursion. Moreover, this chapter extends the illusory influences on temopral variables. Less peak velocity, vertical ground reaction force, anticipatory postural adjustments duration and amplitude occurred when the moving limb was visible during the step execusion. These results show evidence that exploitation of deceptive visual cues can not influence lower limb control with viewing restrictions. The few significant correlations between step displacement and perceptual responses revealed a control separation between perception and action for length estimations using step movements.

The outcomes of chapters 3, 4, and 5 provide insight into the influences of the V-H illusion on perceptual judgments, upper limb, and lower limb motor control. The text in Chapter 6 brings this dissertation to a close through a summary of the main findings for each chapter, dissussion on how these findings relate to the current literature, and direction for future research.

CHAPTER 2. REVIEW OF RELEVANT LITERATURE

INTRODUCTION

The purpose of this chapter is to review the research on visual illusions and present how illusory configurations affect size perception and motor control. In this literature review you will find an overview of different types of visual illusions and their influences on perceptual and motor responses, with an emphasis on the vertical-horizontal (V-H) illusion. It also includes a summary of theoretical considerations and the potential neurological mechanisms linked to visual illusions and concludes with proposed directions for future research.

OVERVIEW OF VISUAL ILLUSIONS

Visual illusion influences on size perception

Illusions affect the perception of specific spatial attributes but do not affect all attributes in a consistent manner (Smeets, Brenner, de Grave, & Cuijpers, 2002). Basic visual illusions affect our perception of size, such as the Brentano or Müller-Lyer illusion (Figure 2.1A), Judd illusion (Figure 2.1B), Kanizsa's compression illusion (Figure 2.2), Oppel-Kundt illusion (Figure 2.3), Ebbinghaus illusion or Titchener circles (Figure 2.4), Ponzo illusion (Figure 2.5) and V-H illusion (Figure 2.6). The Brentano or Müller-Lyer illusion represents a perceived increase or decrease in segment length influenced by surrounding arrowhead-like objects often termed wings (Figure 2.1A). Similar to the Brentano illusion, the Judd illusion wings are oriented in the same direction affecting the perceived center of the winged segment (Figure 2.1B). The Kanizsa's compression illusion occurs when a long rectangular object with substantial width covers most of and is oriented perpendicular to the smaller dimension of one of two identical rectangles, making the smaller dimension of the covered rectangle look shorter than the uncovered one (Figure 2.2). The Oppel-Kundt illusion represents a perceived increase in the length of a horizontal segment

subdivided by multiple identical vertical segments compared to undivided horizontal segment (Figure 2.3). Moreover, the Ebbinghaus illusion, also known as Titchener circles, represents a perceived size difference between two central circles of equal size surrounded by a circular array; the one surrounded by larger circles looks smaller while the one surrounded by smaller circles looks larger (Figure 2.4A). The Ponzo illusion characterizes a perceived greater target located at the converging end of lines than a target located at the diverging end of the lines when the two targets are identical in size (Figure 2.5). The V-H illusion refers to the overestimation of the vertical segment when compared to a horizontal segment of the same length, often presented in an inverted "T" formation (Figure 2.6). In most of these illusions the addition of objects altered the perceptual size; however, orientation of objects altered perceived size for the V-H illusion. Although illusory magnitudes differ slightly among various illusions (Axelrod, Schwarzkopf, Gilaie-Dotan, & Rees, 2017), the illusory influences over general visual perceptions of most healthy people remain fairly consistent in direction of size estimations (i.e., overestimation or underestimation). These illusory influences over size perception can but do not have to produce similar illusory influences over movements.

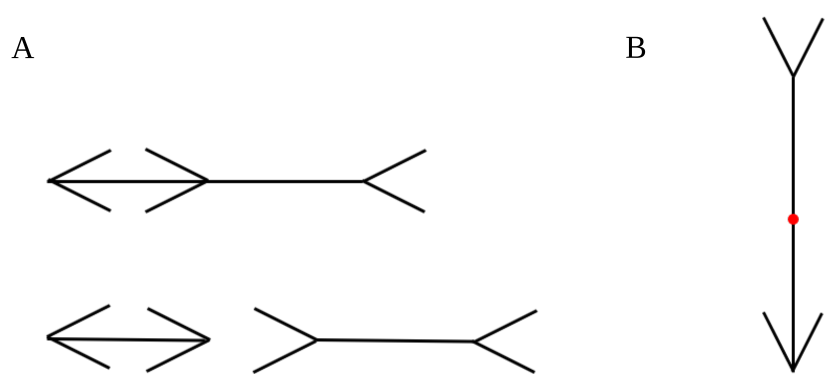

Figure 2.1. A. Brentano illusion (top), a combined form of Müller-Lyer illusion (bottom), in which wings-in correspond to perceived underestimation of the horizontal segment length (left) and wings-outward correspond to perceived overestimation of the horizontal segment length (right) (Porac, 1994). B. Judd illusion. A vertically oriented segment's center placed between two downward facing arrowheads. The red dot located in the center of the segment usually appears closer to the lower arrowhead (Mon-Williams & Bull, 2000).

Figure 2.2. Kanizsa's compression illusion. The dark gray horizontal parts have the same dimensions yet the left one looks narrower (smaller in width). The compression effect is around 5% of the actual width in these conditions (Bruno & Bernardis, 2002).

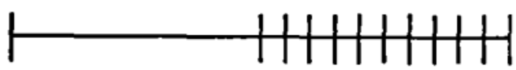

Figure 2.3. Oppel-Kundt illusion. The length of the right half of the horizontal segment subdivided by several vertical segments is perceived longer than the left half of the segment without subdivisions (Ricci, Calhoun, & Chatterjee, 2000; Ricci, Pia, & Gindri, 2004).

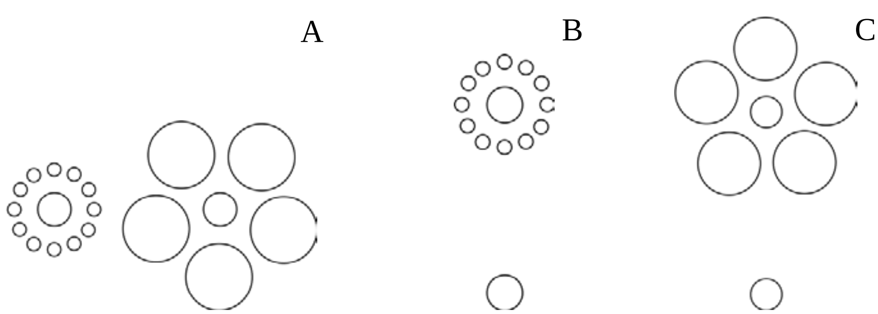

Figure 2.4. Ebbinghaus Illusion (or 'Titchener circles illusion"). A. Dual Ebbinghaus illusion display. Two target circles of equal size are surrounded by a circular array of either smaller (left) or larger (right) circles. Individuals usually report that the central circle surrounded by smaller circles appears larger than the central circle surrounded by larger circles (Wood, Vine, & Wilson, 2013). B and C. Single Ebbinghaus illusion display with an isolated reference circle adopted in perceptual task and without an isolated reference circle adopted in grasping tasks. Individuals

usually report that the isolated circle looks smaller in B and larger in C (Franz, Gegenfurtner, Bulthoff, & Fahle, 2000).

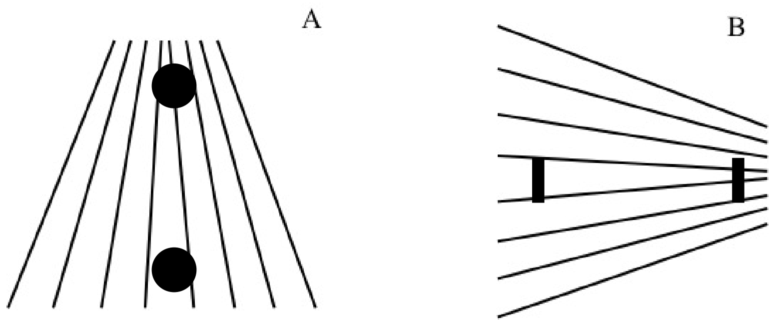

Figure 2.5. Ponzo illusions of the “up and down” orientation (A) and “left and right” orientation (B). A target placed at the converging end of the display appears greater or longer than the target presented at the diverging end when the two targets are equal in size (Bartelt & Darling, 2002; Ganel, Tanzer, & Goodale, 2008).

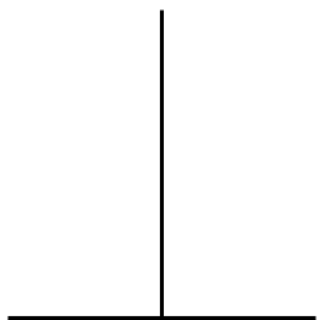

Figure 2.6. Vertical-horizontal illusions of the inverted T (IT). The horizontal and vertical segments are identical in length, but most observers report that the vertical segment appears to be longer (Avery & Day, 1969; Finger & Spelt, 1947; Gavilán, Rivera, Guasch, Demestre, & García-Albea, 2017; Künnapas, 1957; Künnapas, 1957; Künnapas, 1958).

Visual illusion influences on visuomotor control

Visual illusion effects on visually guided actions and manual length estimations can vary. Regardless of comparisons between perception and action, some researchers claim no visual illusory effect on maximum grip aperture (Bartelt & Darling, 2002; Ganel et al., 2008; Gonzalez, Ganel, Whitwell, & Goodale, 2008; Haffenden & Goodale, 1998) or endpoint accuracy (van Donkelaar, 1999). Conversely, illusory effects of visual illusions on maximum grip aperture (Franz, Fahle, Bulthoff, & Gegenfurtner, 2001; Franz et al., 2000; Gonzalez et al., 2008),

pantomime grasps (Bartelt & Darling, 2002), and pointing (Hesse, Franz, & Schenk, 2016) exist in some studies. Although visual illusions do influence temporal aspects, such as, lifting force (Brenner & Smeets, 1996), grasping force (Jackson & Shaw, 2000), reaction times (Smeets & Brenner, 1995), and movement times (Gentilucci, Chieffi, Deprati, Saetti, & Toni, 1996; Smeets & Brenner, 1995; van Donkelaar, 1999), the focus of this section is to review the effects of visual illusions on spatial variables of perceptuomotor control.

Upper limb movements

Many previous investigations, in which researchers assessed the effects of visual illusions on movement control, involved upper limb movements. When individuals made a natural grasping movement with binocular vision, the maximum grip aperture resisted the Ponzo (Brenner & Smeets, 1996; Gonzalez et al., 2008), Ebbinghaus (Gonzalez, Ganel, & Goodale, 2006), and Müller-Lyer (Gonzalez et al., 2006; Heath, Rival, & Neely, 2006; Westwood, Heath, & Roy, 2000) illusions. For instance, with full vision of the experimental setup and hands, people scaled the opening of the dominant hand accurately to the true size of the target object when presented with the Ponzo illusion (Brenner & Smeets, 1996; Gonzalez et al., 2008) and the Müller-Lyer illusion (Heath et al., 2006). Similar to the grasp performances made by the dominant hand on an Ebbinghaus illusion (Gonzalez et al., 2006), use of this illusion did not influence endpoint accuracy of pointing to the center of the target when moving as fast and accurately as possible, regardless of whether the center target appeared larger or smaller in the dual configuration (van Donkelaar, 1999). In contrast, when people grasped an object placed on a Ponzo (Gonzalez et al., 2006; Gonzalez et al., 2008) or Ebbinghaus illusion (Gonzalez et al., 2006) with non-natural grasps, using their ring finger and thumb instead of the index and thumb (Gonzalez et al., 2008), or by the nondominant hand (Gonzalez et al., 2006), the maximum grip

aperture succumbed to this illusion (Gonzalez et al., 2006; Gonzalez et al., 2008). Individuals in one study initiated their movements with a 2-second delay or immediately after a given vertical version of the Müller-Lyer illusory stimulus (Hesse et al., 2016). Subjects started at one end of the illusion, then either pointed to the remembered opposite end of the illusion (memory-based) or pointed to an imagery location in the opposite direction equal in length to the given shaft of this illusion (Imagery-based). Their biased endpoint accuracies under these two conditions suggested that they over-reached in a wings-out configuration and under-reached in a wings-in configuration, indicating that pointing movements in a vertical version of the Müller-Lyer illusion succumbed to the illusory influences (Hesse et al., 2016). Furthermore, with the 2-second movement delay, illusion effects increased in the memory-based condition and reduced in the imagery-based condition. Subjects' grasping movements to a remembered shaft length were also influenced by the Müller-Lyer illusion (Heath et al., 2006). It appears that the use of the non-dominant hand, egocentric cues, an "awkward" grasp, remembered visual cues, and a memory movement delay can alter hand and arm movements according to illusory perceptions. These results leave us wonder if lower limb movements are also altered according to illusory perceptions.

Lower limb movements

Current research confirmed the effects of the Müller-Lyer illusion on lower-limb movements under different viewing conditions paralleled those for upper-limb movements (Glover & Dixon, 2004). Subjects standing with eyes open at one end of the Müller-Lyer illusion configured with wings-in stepped or hopped to place their hallux at the other end of the illusory configuration as accurately as possible, while keeping eyes open (closed-loop), after closing the eyes and stepping/hopping immediately (open-loop), or after closing the eyes and initiating the

stepping/hopping after 3 seconds (open-loop delay). The moved distance (step or hop length) was measured from toe-to-toe for the same foot. The illusory effects on lower-limb movement were smallest in the visual closed-loop condition and largest when visual information was removed and actions were delayed. Clearly, illusory influences over lower limb movement can be reduced by providing visual feedback during task performance and heightened in memory.

Illusory influences over perceptuomotor control remain for upper and lower limb movements. Although cue-related properties, visual access, and type of task can influence such movement, possibly of more interest is the comparison between the influence of visual illusions on perception compared to their influence on perceptuomotor control.

Visual illusion influences on visual perception and visuomotor control

Numerous studies revealed comparisons between the visual illusory influences on perception and action. Results of some of these studies indicated that visual illusions do not bias body movements but influence individuals' perception accuracy. However, others found similar illusory effects on perceptual judgments, visual adjustments, and movements. The focus of this section involves a summary of the literature on these differences and similarities, along with a section, which offers explanations on why these differences or similarities may exist.

Differences between visual perception and perceptuo**motor control**

Evidence supports that the illusory effects on perceptuomotor control differ from that on perception; implying that geometric visual illusions influence human perception often exceed those for action (Aglioti, DeSouza, & Goodale, 1995; Ganel et al., 2008; Haffenden & Goodale, 1998; Haffenden, Schiff, & Goodale, 2001; Mon-Williams & Bull, 2000; Whitwell, Goodale, Merritt, & Enns, 2018) or can include no influence on movements (Mack, Heuer, Villardi, & Chambers, 1985; Westwood et al., 2000). In fact, practice diminished the effects of a Ponzo

illusion on grasping (Gonzalez et al., 2008) but not manual estimations using grip scaling (Whitwell, Buckingham, Enns, Chouinard, & Goodale, 2016). Although manual estimations in this case involve hand movement, it has been used as a perceptual task because it represents the manual read-out of what participants see (Haffenden & Goodale, 1998). Clearly, researchers should carefully separate tasks that directly represent perception from those of action. Care is taken to distinguish the two in the follow text.

Visual illusions can often produce no effects or fewer effects on actions compared with their effects on perception with assessment of visual judgments (Aglioti et al., 1995; Ganel et al., 2008; Haffenden & Goodale, 1998; Haffenden et al., 2001; Mack et al., 1985; Mon-Williams & Bull, 2000; Westwood et al., 2000). Participants, presented with two thin plastic discs, one surrounded by small and one by large circles, were asked to grasp the right disc if they believed disc sizes differed and the left disc for discs of similar size. The illusion (a three-dimensional (3D) version of the Ebbinghaus) was presented for 3 seconds, then lights were turned off prior to movement initiation. Perceptual and motor tasks were conducted under visual open-loop condition in which the visual feedback was not available as they initiated the action. Subjects achieved different maximum and final grasp apertures according to the true disc size and not the perceptual influences of the Ebbinghaus illusion at least when given visual or tactile feedback of the illusory object at the end of the task (Aglioti et al., 1995; Haffenden & Goodale, 1998). Movement accuracy also did not succumb to illusory influences when the same subjects used their index finger to touch the position they believed to be the center of the bar (Mon-Williams & Bull, 2000) or naturally reached, grasped, and lifted the center bar of the Müller-Lyer illusion (Westwood et al., 2000) with full vision in a closed-loop task. Additionally, perceptual accuracy of subjects declined according to the illusion when making a verbal judgment of a pen tip

location along the center of a vertically oriented bar in a Judd illusion (Figure 1B, (Mon-Williams & Bull, 2000)). With modification of the Müller-Lyer illusion, Wrage and colleagues (2000) compared verbal length estimations and open-loop lower limb movements by using the "circle" version of Müller-Lyer illusion rather than a wing at the far end of a shaft in a perceptual judgment task and a blind-stepping task. Subjects stood at one end of the illusion with the circle-in and circle-out configurations at the far end only. In the perceptual task, subjects estimated lengths of the shaft in each configuration. In the stepping task, after viewing the illusory configuration, subjects' vision was occluded and they were asked to step forward so that the heel-to-heel distance matched that of the illusory shaft. The step distance was measured and compared with their verbal length estimates. Subjects performed greater verbal estimations for the shaft length in the circle-out condition than the shaft length in the circle-in condition; however, their step distance was identical in both conditions. These findings demonstrated the differences of the illusory effects on perceptual judgments and actions.

Manual estimates and natural grasping also reflected visual illusions differently (Ganel et al., 2008; Haffenden & Goodale, 1998; Haffenden et al., 2001; Mack et al., 1985; Mon-Williams & Bull, 2000; Westwood et al., 2000). Many researchers interpreted the manual estimation as a perceptual task, in which individuals try to match the distance between two fingers to a given length. Individuals' manual estimates of remembered target sizes were biased by the Ebbinghaus (Haffenden & Goodale, 1998), Müller-Lyer (Westwood et al., 2000), and Ponzo (Ganel et al., 2008) illusions. However, when they were asked to make a grasping movement to remembered targets within each illusion, their maximum grip aperture accurately matched the true size of the targets, contributing to the presence of a significant difference between manual estimations and maximum grip aperture (Ganel et al., 2008; Haffenden & Goodale, 1998; Westwood et al.,

2000). This clear dissociation between the maximum grip aperture during the open-loop grasping task and the separation between the index finger and thumb during open-loop manual estimates was confirmed, regardless of involvement of control condition in which the central disc of the Ebbinghaus illusion was surrounded by circles of the same size (Haffenden & Goodale, 1998). One can obviously see how tactile feedback provided at the end of task performance limited illusory influences over movement. Results in the next section reveal that lack of illusory influences are not limited to grip aperture or movements toward three-dimensional (3D) objects.

Visual illusions can also bias pantomime movements and perception differently. In this case pantomime movements represent movements to remembered targets without providing visual or tactile feedback. The effects of a visual illusion on visual judgments and open-loop bimanual pantomime movements differed (Bruno & Bernardis, 2002). In a visual judgment task, subjects compared the length of the rectangle in the Kaniza's compression illusion to the length of one of a set of comparison rectangles next to it, and reported which of the two rectangles appeared longer. Visual perceptions differed according to the illusion. In contrast, for open-loop bimanual pantomime movements, subjects were instructed to reach towards a remembered target by extending the arms to position the hands next to the left and right sides of the remembered target. Subjects scaled the left hand and right hand accurately to the true size of the rectangle of the illusion. In this case, individuals' visual judgments reflected the effects of the Kaniza's compression illusion but the open-loop bimanual pantomime movements did not, suggesting limited illusory influences over bimanual pantomime movements when in recent memory.

Not only the use of closed-loop control but also the use of open-loop control can result in illusory influences over perception and not movement, supporting differences between perception and action. Some researchers report that an illusory bias on a goal-directed action will

depend on the relative importance of advanced planning such that illusions utilizing feed-forward inputs, like those needed for open-loop tasks, will differ from those used during online control through feedback mechanisms (Glover & Dixon, 2004), like those needed for closed-loop tasks. Although perceptual influences over movement exist and can direct errors in planning which utilizes feed-forward visual inputs, these errors can be corrected online utilizing visual feedback during the movement and might influence each phase of movement differently. This idea provides support for a separation between perception and action (Glover & Dixon, 2004). Interestingly, results of the next section reveal similar illusory influences over perception and action that contradict the findings just presented.

Similarities between visual perception and visuomotor control

In some cases, effects of visual illusions on human perceptions of size are in accordance with effects on movement output (Daprati & Gentilucci, 1997; de Grave, Brenner, & Smeets, 2004; Elliott & Lee, 1995; Franz et al., 2001; Franz et al., 2000; Gentilucci et al., 1996; Heath et al., 2006; Meegan et al., 2004; Melmoth, Tibber, Grant, & Morgan, 2009; Predebon, 2004; van Donkelaar, 1999). In these studies researchers found no evidence supporting the dissociation between perception and action.

Verbally judging the relative size of illusions and naturally grasping objects on visual illusions were consistently biased by the illusion. Subjects verbally reported "long", "short", or "same" according to their perceptions of the remembered shaft length of Müller-Lyer illusion relative to a reference segment and pointed with a stylus to the remembered end of Müller-Lyer illusion (Meegan et al., 2004). Responses and movements followed illusory influences so that they made a longer pointing distance for "wings-out" configuration, which was verbally reported "long", for example. In other studies, without the presentation of the original Ebbinghaus illusion

like shown in Figure 2.4A that had two identical discs encircled by either greater or smaller circles, subjects were provided with one disc with circular surrounds and an isolated disc (Figures 2.4B, 2.4C) (Franz et al., 2000; Marotta, DeSouza, Haffenden, & Goodale, 1998; Pavani, Boscagli, Benvenuti, Rabuffetti, & Farne, 1999). Subjects, who adjusted the diameter of the isolated circle to match the center circle of the illusion, made it larger for Figure 2.4B and smaller for Figure 2.4C and altered their maximum grip aperture when reaching to grasp the 3D central circle so that it was larger for Figure 2.4B and smaller for Figure 2.4C (Franz et al., 2000). Unlike previous research (Aglioti et al., 1995), subjects recruited in these studies (Marotta et al., 1998; Pavani et al., 1999) reached and grasped with a visible hand and target during movements producing equal illusory effects on perceptual judgments and maximum grip aperture. These findings provide evidence to suggest that with a natural grasp, that produced by the thumb and index finger, individuals' maximum grip aperture succumbed to the single array version of the Ebbinghaus illusion. Thus, visual adjustments, relative size judgments, and grasping a visible target were affected by visual illusions.

Visual feedback during movements can change illusory effects on movement. Movement accuracy of subjects declined according to the Judd illusion when subjects used the unseen index finger to touch a position underneath the display table where they believed the center of the bar to be (Mon-Williams & Bull, 2000). Authors report that illusory influences in this case exceeded the illusory influences for perceptual judgements of the bar center. To assess the comparisons between verbal length estimations and open-loop lower limb movements, Wrage and colleagues (2000) conducted an experiment by using the "circles" version of Müller-Lyer illusion rather than wings at the ends of a shaft in a perceptual judgment task and a blind-stepping task. Although the motor results were presented previously in this document, here we present the

perceptual portion of the study and give results for perceptual and motor comparisons. Subjects stood 1.5 m away from the nearest end of the illusion and verbally estimated the length of the shaft of the "circles-in" and "circles-out" configurations at both ends. After viewing the illusory configuration, they turned 90 degrees to their left, and performed a blind forward step to match the length of the shaft without vision (Wraga et al., 2000). Greater estimations existed for the shaft of the "circles-out" configuration than of the "circles-in" configuration for both tasks suggesting no significant difference between visual perceptions and open-loop stepping movements with the complete illusion in recent memory. Therefore, visual illusion effects on open-loop hand reaching movements equaled stepping.

Illusions can also bias perceptual accuracy of hole size and motor planning control for aiming performances. Subjects asked to draw life-sized replicas of each target circle (i.e., the center of the Ebbinghaus illusion) projected on a putting green, drew larger circles when the target circle looked larger, thus was surrounded by small circles (left panel, Figure 2.4A), than when the target circle looked smaller, thus was surrounded by large circles (right panel, Figure 2.4A) (Wood et al., 2013). Moreover, subjects' putts towards the target circle of the same illusory projections, which disappeared immediately after putt initiation, produced errors to the closest edge 3.64 cm smaller for the larger looking target than errors for the smaller looking target. Illusion-based biases in perceptions of target size and performance errors existed for these far-aiming performances (Wood et al., 2013), providing additional evidence of illusory influences for open-loop performances can imitate those for perceptions, yet disagree with others (Aglioti et al., 1995; Haffenden & Goodale, 1998; Wood et al., 2013).

Manual estimations and pantomime grasping were equally influenced by the Müller-Lyer illusion (Westwood et al., 2000). In an open-loop experiment, the Müller-Lyer illusion

influenced subjects' perceptions (manual estimations) and the natural grasping movements, without visible targets, background, and hand (Westwood et al., 2000). As subjects opened the thumb and index finger to match the perceived length of the center bar and held for 2 seconds, their corresponding grip aperture was biased by this size illusion. Moreover, manual estimates and the maximum grip aperture of grasping and lifting the center of a bar in this illusion were consistent with its true width. Thus, regardless of the open-loop and closed loop conditions, instead of natural grasping, pantomime movements towards remembered targets and manual estimations were susceptible to the Müller-Lyer effect equally. The focus of the next section is to explain the conflicts among studies and provide readers greater insight into the existence of illusory influences over perceptuomotor control.

Explaining the differences and similarities between visual perception and perceptuo**motor control**

Reports on the differential effects of visual illusions on perceptual judgments and goal-directed action exist (Bartelt & Darling, 2002; Ganel et al., 2008; Glover & Dixon, 2004; Haffenden & Goodale, 1998; Jackson & Shaw, 2000; Mon-Williams & Bull, 2000; van Donkelaar, 1999; Westwood et al., 2000; Whitwell & Goodale, 2017; Wraga et al., 2000). Various explanations may account for such differences. Differences and similarities between perception and action in these studies might be due to variations in methodologies (Bruno, Bernardis, & Gentilucci, 2008). Factors that modulate the illusion effects on pointing include type and size of illusion, measuring device, plane of stimulus presentation, direction of movement, target location, location of stimulus presentation in visual field, conditions at the movement planning phase, visual feedback during the movement performance, starting position

and direction of approach, number of trials for each experimental condition (Bruno et al., 2008), and delays after visual presentation (Glover & Dixon, 2004).

Mon-Williams and Bull (2000) proposed that if a part of illusory background was occluded during the reaching movement, individuals would be less influenced by the Judd illusion during the reach compared to the perceptual task in which the whole illusion was visible. Moreover, viewing conditions would influence the illusion effects. In an open-loop task, individuals produced biased perceptual judgments and biased maximum grip aperture when viewing illusions monocularly; however, in a binocular condition, subjects scaled their grip precisely to the true size of the target disc (Marotta et al., 1998). Thus, monocular movements are more influenced by visual illusions. Inconsistent visual stimuli also resulted in different findings cross studies. When the single illusory-circles array of the Ebbinghaus illusion was presented, the illusory effect on movement control is similar to perception, while such illusory effect on movement and perception showed different when viewing a dual display. Researchers also do not have a golden standard to classify perception and action. Some studies used manual estimations as their perceptual task (Bartelt & Darling, 2002; Westwood et al., 2000), while other used verbal reports (Pavani et al., 1999), such as oral length estimations, to clearly distinguish the perception and action. Franz et al. (2000) proposed that the different outcomes of perception and action are due to an incomplete match between the perceptual task and the motor task. Different experimental procedures involving blocking part of illusion by fingers when grasping a target, the use of monocular vision, inconsistent visual stimuli, and use of different perceptual tasks might explain different effects of visual illusions on perception and action.

Practice effects can change the illusory effects on movements and perceptions. For example, five practice trials with tactile feedback eliminated the Ponzo illusion on grasping but

did not attenuate this illusion on manual estimations (Whitwell et al., 2016). The perceptual effects of the Müller-Lyer illusion attenuated over repeated illusion presentations, while a similar decrease after repeated grasp trials was also observed on the Müller-Lyer illusion (Heath et al., 2006). Instead of nature grasps by thumb and the index, grasps with the thumb and ring finger succumbed to Müller-Lyer and Ponzo illusions early in performance but became less influenced with practice (Gonzalez et al., 2006). The illusion magnitudes of actions decrease as the number of trials increases for the Müller-Lyer illusion (Bruno et al., 2008). Therefore, studies involving practice trials produced less illusory influences on movements, which created differences between visual perception and motor control.

Use of open-loop and closed-loop tasks would slightly change illusory effects on movement. The dissociation of illusory influences between grasping and perception was observed in open-loop tasks (Franz & Gegenfurtner, 2008). After viewing a Müller-Lyer illusion for 2 seconds, without invisible hand and targets during movements, subjects' actions were influenced in open-loop trials and were not influenced in closed-loop trials when the two types of trial were set by blocks (e.g., consecutive open-loop trials in a block). However, as the open-loop trials and closed-loop trials were interweaved randomly, all performances were influenced by this illusion (Heath et al., 2006). Therefore, not only do the open-loop and closed-loop tasks themselves produced different illusions but so does task presentation order.

Lastly, eye movements could be a factor causing different outcomes cross studies. Most studies did not adopt an eye-tracker to record subjects' eye movements, yet reports of fixation stability and gaze direction may influence perceptual judgments. In one study fixation instability was shown positively correlated with the strength of visual illusions (Murakami, Kitaoka, & Ashida, 2006). In antoher study fixating on a illusory configuration produced greater illusory

influences compared with a free gaze condition (Chouinard, Peel, & Landry, 2017). Further research involving fixation stability and gaze direction on perceptual judgments and perceptuomotor control would potentially help explain outcome differences across studies.

VERTICAL-HORIZONTAL (V-H) ILLUSION

V-H illusion research

The V-H illusion has been studied widely. No matter which version of the V-H illusion, two corresponding segments are perpendicular (Figure 2.7). The horizontal segment parallels the body's medial-lateral axis, while the vertical segment parallels the body's longitudinal axis when the configurations are placed in a vertical/frontoparallel plane. Horizontal plane projections of the illusion, on a flat desktop for example, reveal a changed vertical segment so that it parallels the body's anterior-posterior (AP) axis. Slanted plane projections of the illusion, like on a drafting board table top, produce components of the vertical segment in multiple directions projected in longitudinal and AP exes of the body. Examples of V-H illusory influences on perception exist for frontoparallel (e.g., (Masin & Vidotto, 1983; Mikellidou & Thompson, 2013)) and horizontal (e.g., (Finger & Spelt, 1947)) plane configurations. Moreover, people observe horizontal and vertical cues within the environment and can use these allocentric cues for orientation (Klein, Li, & Durgin, 2016) and motor control (Elliott, Vale, Whitaker, & Buckley, 2009; Foster, Buckley, Whitaker, & Elliott, 2016; Foster et al., 2015), making their potential use for perceptuomotor control attractive. Methods of investigating the illusory effects of the VH illusion on perceptions differ. Subjects were asked to determine whether the vertical segment seemed longer, shorter or equal to the horizontal segment. Responses included keypresses or a response box with two (Charras & Lupiáñez, 2010; Mikellidou & Thompson,

2013; Renier, Bruyer, & De Volder, 2006; Wolfe, Maloney, & Tam, 2005) or three (Thompson & Schiffman, 1974) choice options, oral reports of the length of a segment in units (Masin & Vidotto, 1983), visual adjustments of the length of one of two segments (Finger & Spelt, 1947; Hamburger & Hansen, 2010), segment drawing to match the length of a given segment (Gavilán et al., 2017), and directions to the experimenter to move one of two poles until they considered the distance between the two poles looked equal to the height of the taller pole (Klein et al., 2016). Unfortunately, the variations among studies can produce subtle differences that may account for different outcomes across studies difficult to identify.

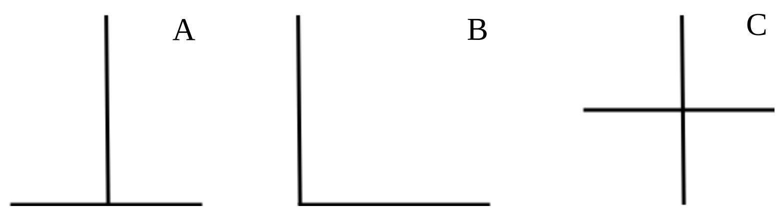

Figure 2.7. Vertical-horizontal illusions of the inverted T (A), L (B). The horizontal and vertical segments are identical in length, but most observers report that the vertical segment appears to be considerably longer (Avery & Day, 1969; Künnapas, 1957). The vertical-horizontal illusion plus sign (C). Most observers report that the two segments appear to be identical (de Montalembert & Mamassian, 2010; Gavilán et al., 2017) but sometimes the vertical segment is reported as longer than horizontal one (de Montalembert & Mamassian, 2010).

Understanding V-H illusory influences over movement control with vision available would eliminate darkness induced safety issues, while possibly encouraging voluntary movements. As mentioned previously, older adults produced greater toe clearance when ascending stairs with multiple vertical segments on the rise and horizontal segments on the tread components of stairs compared to ascending plain stairs (Foster et al., 2015). Although the greater toe clearance can decrease the trip potential (Zietz, Johannsen, & Hollands, 2011), these results revealed that V-H illusory influences exist in recent memory even with other allocentric cues available because people cannot view the stair rise and tread simultaneously while stepping. Whether V-H illusory influences on perceptuomotor control persist during continuous viewing of

the illusion during movement remains to be determined, as reduced illusory influences over movement control existed for people allowed to view the illusion throughout the movement (Mon-Williams & Bull, 2000; Servos, Carnahan, & Fedwick, 2000).

Perceptual variations to the V-H illusion

Influences of the V-H illusion on perception are not limited to the standard inverted T (IT) configuration (Figure 2.7A, 2.8A-1). Although, the V-H illusion magnitude for IT commonly exceeds the configuration "L" (Figure 2.7B, 2.8B-1) (Avery & Day, 1969; Charras & Lupiáñez, 2009; Finger & Spelt, 1947; Gavilán et al., 2017; Künnapas, 1957; Wolfe et al., 2005) and an asymmetrical inverted T (Figure 2.8D-1) (Josev, Forte, & Nicholls, 2011; Wolfe et al., 2005), many observers perceive a longer vertical segment in each case. The illusory influences do not exist for horizontal and vertical segments of the same length in the plus sign configuration (Figure 2.7C, (de Montalembert & Mamassian, 2010; Gavilán et al., 2017)). Therefore, bidirectional bisection can alter V-H illusory perceptions. The focus of this section is to review the V-H illusory influences on size across varied stimuli.

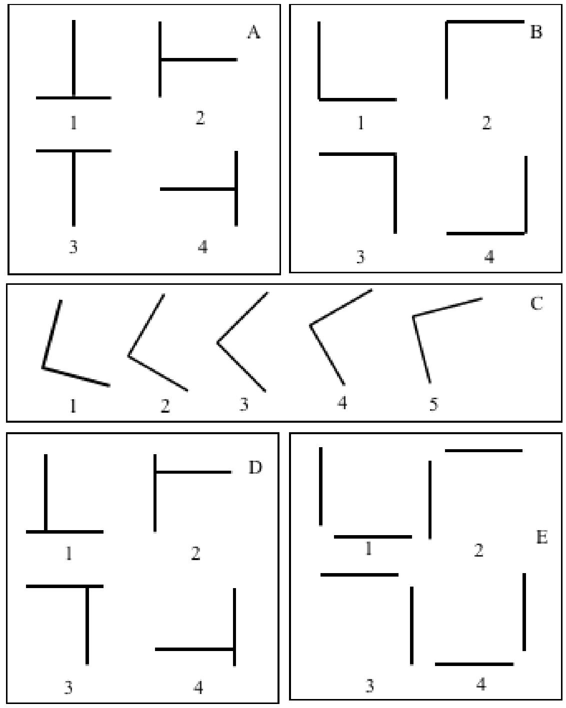

Figure 2.8. Different configurations of vertical-horizontal illusion in literatures. IT (A1), 90°-rotated T (A2), 180°-rotated T (A3), 270°-rotated T (A4); L (B1), 90°-rotated L (B2), 180°-rotated L (B3), 270°-rotated L (B4); L with 15° (C1), 30° (C2), 45° (C3), 60° (C4), 75° (C5) clockwise rotation. Modified Inverted-T (MIT)(D1), 90°-rotated MIT (D2), 180°-rotated MIT (D3), 270°-rotated MIT (D4); Non-connect L (NCL) (E1), 90°-rotated NCL (E2), 180°-rotated NCL (E3), 270°-rotated NCL (E4).

Effects of the V-H illusion on relative length perceptual judgments consistently show that the vertical segment appears longer than the horizontal one. Table 1 indicates that the length of vertical segment looks 6.5%-28% greater than the horizontal segment when healthy individuals view these segments oriented in an IT, the most robust effects of the V-H illusion on perception (Figure 2.7A, Figure 2.8A-1). The V-H illusion also impacts the intersection of two segments in the L shape configuration. As the bisection is eliminated (L shape, Figure 2.7B, Figure 2.8B-1), the vertical length illusion magnitude reduces to 10% or less (2.89%) over the horizontal length (see L column, Table 2.1). The illusion extent decreases by 10.7%-13.4% from a symmetrical inverted T (Figure 2.7A, Figure 2.8A-1) to an asymmetrical inverted T (Figure 2.8D-1, 2.8D-2), and slight decreases of 0.1%-1.4% from the asymmetrical inverted T to the L can also exist

(Figure 2.7B, Figure 2.8B-1, 2.8B-4) (de Montalembert & Mamassian, 2010; Wolfe et al., 2005). These outcomes indicate that the bisection of the inverted T produces a stronger illusory influence on visual perceptions than the asymmetrical inverted T and L. With less consistent V-H illusion than the symmetrical and asymmetrical inverted T and L configurations, the horizontal segment in a cross/plus sign (+) configuration (Figure 2.7C) looks equal to (Charras & Lupiáñez, 2009), or shorter than the vertical segment; approximately 5% underestimation of the horizontal segment (de Montalembert & Mamassian, 2010), 1.44% underestimation for the horizontal segment for a manually adjusted horizontal segment, and 6.96% overestimation for the vertical segment for a manually adjusted vertical segment (Gavilán et al., 2017).

Table 2.1. The different V-H illusion magnitudes among research studies.

Author's name	**Inverted T**	**Horizontal T**	**L**	**+**
Kunnaps (1955a)	16%	N/A	6%	N/A
Vishton et al. (1999)	20%	N/A	N/A	N/A
Charras & Lupiañez (2010)	16%	N/A	6%	N/A
Mamassian and de Montalembert (2010)	17%	-9%	5%	5%
Mikellidou & Thompson (2013) Vertical segment in configuration > single vertical segment	8.7%	N/A	N/A	-7.1%
Mikellidou & Thompson (2013) Vertical segment in configuration > single horizontal segment	7%	N/A	15%	NS
Mikellidou & Thompson (2013) Single vertical segment > horizontal segment in configuration	-6%	N/A	4%	-14%
Cai et al. (2017)			10%	
Fraisse and Vautrey (1956)			11.5%	

Note: positive values indicate that the vertical segment appears longer than horizontal segment of the illusory configuration or the segment referenced; negative values indicate that the vertical segment appears shorter than horizontal segment of the illusory configuration or the segment referenced. N/A indicates that the study does not involve the configuration. NS indicates no significant differences between compared segments.

The V-H illusion still exists when comparing the horizontal segment or the vertical segment within a configuration to an isolated segment (Table 2.1) (Mikellidou & Thompson, 2013), or when the two segments are presented separately for an IT (4%-7%) (Masin & Vidotto, 1983; Mikellidou & Thompson, 2013) or L (Figure 2.8E) (1%-8.5%) (Finger & Spelt, 1947; Hamburger & Hansen, 2010). As illusory configurations were rotated 15°-270° clockwise (see examples in Figure 2.8), subject's visual perceptions remained deceived by these configurations (Avery & Day, 1969; Charras & Lupiáñez, 2009; Charras & Lupiáñez, 2010; Chouinard et al., 2017; de Montalembert & Mamassian, 2010; Finger & Spelt, 1947; Gavilán et al., 2017; Hamburger & Hansen, 2010; Künnapas, 1955a; Thompson & Schiffman, 1974). Adjustment of the segments intersection and configuration orientation did not remove illusory effects of these configurations.

The size of configurations showed different illusory magnitudes cross studies. Small configurations produced stronger V-H illusions than large ones (Thompson & Schiffman, 1974); however, compared to small V-H illusions, large-scale outdoor V-H illusions produced greater illusion amplification (25%) (Klein et al., 2016). In addition, the illusion was stronger when time was limited than the conditions with unlimited time (Fraisse & Vautrey, 1956). Women showed stronger illusion bias than men without time limitation and no difference in tachistoscopic perception (with time limitation – 0.2s and 1s) (Fraisse & Vautrey, 1956). Thus, illusory effects changed with size of V-H illusory configurations, sex, and time limitations.

Theoretical links to the V-H illusion

Visual field explanation

Some researchers explored why the V-H illusion exists. One theory used to explain part of the V-H illusion is the shape of the visual field produced by the natural elliptical orbit of the

eye (Gavilán et al., 2017; Houck, Mefferd, & Greenstein, 1972; Künnapas, 1955b; Künnapas, 1957; Williams & Enns, 1996). Due to location of the eyes in humans, the visual field has the form of a horizontally oriented ellipse (i.e., with a longer horizontal axis than vertical axis) (Künnapas, 1955a, 1957). If there is a vertical and a horizontal segment of equal length in the center of this visual field, the distance from the top end of the vertical segment to the boundary of the visual field is shorter than the distance from the right end of the horizontal segment to the boundary (Künnapas, 1957). Therefore, the vertical segment can appear longer than the horizontal segment. The size/orientation of a frame influences V-H L illusion enclosed within this frame. An increase of the vertical component with a smaller horizontal component of the frame reduces the drawn length of a vertical segment relative to a frame with equal horizontal and vertical components or with decreased vertical components and larger horizontal components (Künnapas, 1955b; Künnapas, 1957). Moreover, the illusory effects are similar when an illusory figure is located in the center of a rectangular and an ellipse. Similarly, overestimation of the vertical segment within a square is much like that for a circle (Künnapas, 1957).

Studies using monocular and binocular viewing fields provide additional evidence to support elliptical field effects on the V-H illusion. Subjects showed a larger V-H illusion with binocular (2.47% overestimation of the vertical segment difference) than with monocular (1.36% underestimation the horizontal segment) presentation (Prinzmetal & Gettleman, 1993). The authors concluded that the illusion effect reduced with monocular presentation, because the monocular visual field is more circular than the binocular one (Prinzmetal & Gettleman, 1993). Furthermore, a 7.1% V-H illusion effect in normal light and 4.8% illusion effect in a dark surround exists (Künnapas, 1957). Authors suggest that the elimination of the elliptical visual

field that occurs with binocular vision clearly reduced illusory influences, producing differences between illumination conditions. No illusory differences between monocular and binocular viewing of the V-H segments was obtained in darkness (Avery & Day, 1969; Prinzmetal & Gettleman, 1993). Because viewing field boundary and darkness does not eliminate V-H illusory effects on perception, the evidence also indicates the existence of other influences which are not well understood (Künnapas, 1957).

Bisection explanation

The bisection theory, in which the bisected segments look shorter than that not bisected (Finger & Spelt, 1947; Gavilán et al., 2017; Künnapas, 1955a; Renier et al., 2006; Wolfe et al., 2005), is another theory used to explain the existence of the V-H illusion. The overestimation of a vertical segment often reduces with changes in the segment configuration (Wolfe et al., 2005). For example, in an IT configuration (Figure 2.7A), the vertical segment appears longer than that of a non-bisected L configuration (Figure 2.7B). When comparing the relative length of two segments, in an IT configuration, 99.5% of subjects' responses were that the vertical segment (bisecting segment) looked longer than the horizontal (bisected). In a 90°-rotated T configuration (Figure 2.8A-2), when people adjusted the length of a bisecting segment to match a bisected segment, the length of the bisecting segment they made was 2.64% shorter than the non-bisected segment, which indicates that people perceived a shorter bisected segment. Similarly, when adjusting the length of a bisected segment, people perceived a longer bisecting horizontal segment (7.64%). Researcher also found that the 90°-rotated T produces an effect in which the horizontal bisecting segment looked longer than the vertical bisected segment (Künnapas, 1955a). These findings suggest that segment bisection contributes to the V-H illusion (Gavilán et al., 2017).

Depth explanation

Another explanation of the V-H illusion involves the pictorial depth theory, in which people overestimate the vertical segment because they perceive that the vertical segment extends in depth (the anterior direction when not presented vertically) unlike the medial-lateral (M-L) positioning of the horizontal segment, a set distance away from the viewer (Girgus & Coren, 1975; Gregory, 1991, 1997; Williams & Enns, 1996). Thus, the vertical segment projects a slightly smaller length on the retina and people overcompensate for this shorter length to report that the length of the vertical segment appears longer than that of the horizontal segment (Girgus & Coren, 1975; Gregory, 1991, 1997; Williams & Enns, 1996).

Moreover, more than one theory has been proposed to explain the overestimation of the vertical segment in the V-H illusion. For instance, the combination of the visual field theory and depth theory (Williams & Enns, 1996), the combination of the bisection theory and visual field theory (Gavilán et al., 2017) could account for the overestimation of the vertical segment of V-H illusions.

Differences between visual perception and visuomotor control for the V-H illusion

Similar to other illusions, V-H illusions do not always affect perceptual judgments and movements similarly. Perception and action disparities existed for the V-H illusion in a study in which prior to the grasping task, subjects were told to respond “same” or “different” when presented with IT stimuli on a horizontal plane (Servos et al., 2000). Individuals reported “same” for a stimulus with shorter vertical than horizontal segments and “different” for a stimulus with similar segment lengths. When asked to reach and grasp the horizontal segment of an inverted T stimulus of equal or larger size to the vertical segment with visual feedback available, the subjects’ maximum grip aperture scaled according to the veridical stimulus. Thus, with online

feedback no detectable illusory influences existed for action. Without continuous visual feedback of an open-loop pantomime, reaching task, subjects separated the thumb and index finger as if picking up a vertical segment in the V-H illusion. Their mean grip aperture was slightly affected by this illusion with 3% overestimation of the vertical segment, which was significantly smaller than 20% overestimation of the vertical segment in a perceptual task (Vishton et al., 1999). Therefore, the V-H illusion did not influence individuals' upper limb movements despite available visual feedback and pantomime movements without visual feedback.

Similarities between visual perception and perceptuomotor control for the V-H illusion

Although the number of research studies on whether V-H illusions bias motor control is not as large as those for other visual illusions, the presence of few studies on V-H illusions claim that V-H illusions can affect perceptual judgments and temporal (Raudsepp & Djupsjobacka, 2005) and spatial (Elliott et al., 2009; Foster et al., 2016; Foster et al., 2015; Vishton et al., 1999) body movements, similarly. Results of two experiments within one study suggest that grasping movements can be influenced by the V-H illusion (Vishton et al., 1999). In one experiment subjects viewed a two-dimensional (2D) inverted triangle with a bisecting line segment or square prior to movement. Then with eyes closed subjects reached with the dominant arm and adjusted their grasp to the object size as if grasping 3D object with the index and middle fingers on the top corners and thumb at the triangle tip or the bisection point at the bottom of the square (see Figure 2.9). Results revealed that final grip scaling of the imagined 3D object on a 2D surface was affected by the V-H illusion such that the bisecting vertical segment of the triangle resulted in smaller mean horizontal index to middle finger distance than the square. Illusory vertical magnitude/horizontal magnitude of the triangle was also perceived as greater than that of the square to suggest similar influences on perception and action for this configuration (Vishton et

al., 1999). In this instance motor grasping tasks aligned with perception when people receive no visual or tactile feedback of the illusory object during the movement.

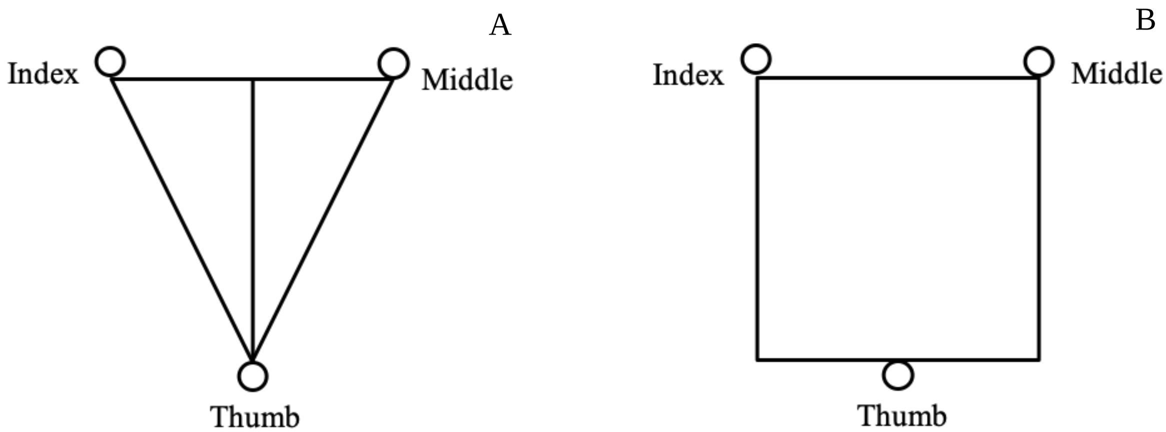

Figure 2.9. A figure approximating the 2D printed stimuli used in Vishton et al.'s (1999) study. Participants viewed the printed triangle (A) and square (B) and reached for them as if to grasp a thin object with three fingers. Circles represent the expected location for middle finger, index finger, and thumb, respectively. Note, the same positioning for each finger.

Recently, researchers applied the V-H illusion to lower limb movements, such as stepping on staircases (Elliott et al., 2009; Foster et al., 2015) and walking across an obstacle (Foster et al., 2016). In a one staircase study (Elliott et al., 2009), a modified 3D V-H illusion version was applied to a staircase including two different presentations. In the first presentation (V-staircase), several vertical stripes were presented on the staircase riser, which was parallel to the frontal plane of the body, and horizontal stripes were on the tread surface of the staircase on the horizontal plane. The horizontal stripes and vertical stripes switched in the second presentation (H-staircase). Individuals were asked to judge the height of a staircase by orally. The average perceived staircase height in V-staircase was greater than that in H-staircase. These perceptual outcomes are in accordance with their stepping results. Individuals showed greater vertical toe clearance of the lead-limb when stepping on the V-staircase than the H-staircase.

Two other studies further confirmed the effects of the V-H illusion on foot toe clearance when stepping on more than one staircase and crossing a low-height obstacle (3, 5, or 7 cm). Individuals lifted the lead foot higher when the vertical stripes were placed on the front surface of the staircases (Foster et al., 2015) or the obstacle (Foster et al., 2016). Thus, in these open-loop tasks, lower limb movements were influenced in the direction of the V-H illusion.

NEUROLOGICAL MECHANISMS

Neural areas used for visual perceptions

Visual perceptions are processed by a ventral visual system that includes occipitotemporal brain structures; particularly, visual information starts with primary visual area (V1, Brodmann's area 17) in the occipital lobe and goes through the secondary visual cortex (V2), then through the visual area V4 (V4), and to the inferior temporal lobe. This system helps human recognize properties of objects (Goodale & Milner, 1992), such as, sizes, colors and shapes.

As people are instructed to perceive the sizes of configurations which produce visual illusions, they recruit other brain structures, such as parahippocampal cortex (Axelrod et al., 2017). Geometric visual illusions influence individuals' visual perceptions differently. Exploring the neural mechanism would be a good way to understand why people would be perceptually influenced by one illusion and less influenced by another. For example, people are less influenced by the V-H illusion than the Ebbinghuas and Müller-Lyer illusions, which may be explained by the latter two sharing the same neural area-the parahippocampal cortex (Axelrod et al., 2017).

Functional neuroimaging techniques, functional Magnetic Resonance Imaging (fMRI) (Mendola, Dale, Fischl, Liu, & Tootell, 1999; Stanley & Rubin, 2003), positron emission

tomography (Ffytche & Zeki, 1996; Larsson et al., 1999), Electro-Encephalography (Grice et al., 2003; Herrmann & Bosch, 2001; Korshunova, 1999; Murray, Foxe, Javitt, & Foxe, 2004; Pegna, Khateb, Murray, Landis, & Michel, 2002; Proverbio & Zani, 2002; Senkowski, Röttger, Grimm, Foxe, & Herrmann, 2005; Sugawara & Morotomi, 1991), Magneto-encephalography (Halgren, Mendola, Chong, & Dale, 2003; Ohtani et al., 2002), and transcranial Magnetic stimulation have been used in studies for investigation of the Kaniza's illusion. Although many researchers found that the primary visual area is activated when viewing a Kaniza's illusion (Halgren et al., 2003; Larsson et al., 1999; Seghier et al., 2000), some found weak activations (Mendola et al., 1999); or did not observe activations in V1 area (Brighina et al., 2003; Murray et al., 2004). Those who found no activations in V1 area observed activations in other regions, such as, different parts of the lateral occipital gyrus, including V5 area {Murray et al., 2002; Pegna et al., 2002; Ritzl et al., 2003), the right parietal cortex (Murray et al., 2002) and the lateral occipital complex region (Murray et al., 2004; Murray et al., 2002; Pegna et al., 2002), the right extrastriate cortex (Brighina et al., 2003), and the posterior parietal regions (Murray et al., 2004). Moreover, activity in the anterior occipital lobe (Mendola et al., 1999) and the lateral occipital region (Murray et al., 2004; Murray et al., 2002; Pegna et al., 2002; Stanley & Rubin, 2003) corresponded to people presented with visual illusions. People novice to visual illusion presentations showed different fMRI activations compared to people with experience (Stanley & Rubin, 2003), which indicated that the individualism exists in visual illusions. These outcomes are confirmed in behavioral data which show that different people possess different perceptual cut-offs for size differences in perpendicular segment lengths used in the V-H illusion (Bartelt & Darling, 2002).

Patients with hemi-neglect, diagnosed with temporal, parietal lobes, thalamic, and capsulo-lenticular lesions, were more influenced by visual illusions than controls (de Montalembert & Mamassian, 2010). Compared to participants in a control group (5%), the average overestimation of the vertical segment in an L-shape configuration for people with hemi-neglect was 11%, which was similar to the average magnitude of 10% for people with right brain damage (de Montalembert & Mamassian, 2010). Similarly, when viewing an IT configuration, patients with hemi-neglect, patients with right brain damage, and participants in control group (without any brain damage) performed 22%, 20%, and 17% overestimation of the bisecting segment of the V-H illusion, respectively (de Montalembert & Mamassian, 2010).

Neural areas used for visuomotor control

Based on the two-visual-pathway hypothesis, human perceptions and motion are mediated by separate visual systems (Milner & Goodale, 2008). Moreover, other researchers have supported this hypothesis by including participants with optic ataxia (Milner et al., 2001), and visual form agnosia (Servos & Goodale, 1995). During goal-directed action, individuals recruit not only the ventral visual system but also a dorsal visual system, which consists of occipitoparietal regions (Goodale & Milner, 1992; Milner & Goodale, 2008). Both visual systems start with V1 and project through V2 and split at V2. The dorsal pathway projects through the dorsalmedial area (V6) and the middle temporal area (V5), and then to the posterior parietal cortex (Goodale & Milner, 1992; Milner & Goodale, 2008).

Manual estimates of stable grip aperture made by opening the thumb and the index are affected by perceptual processing and are under the control of the ventral stream (Ganel & Goodale, 2003; Haffenden & Goodale, 1998). Therefore, the ventral stream (vision-for-perception) mediates visual judgments and manual estimations. On the other hand, when people

direct movements on geometrical visual illusions, the dorsal stream (vision-for-action) takes the responsibility for maximum grip aperture of grasping and the endpoint accuracy of pointing (van Donkelaar, 1999).

SUMMARY

Summary of V-H influences

Numerous studies on V-H illusions have included illusory effects on perceptions, by adopting various V-H illusory configurations (e.g., L-shape and IT), investigation methods (relative judgment and metric length estimation), orientations (rotating the configurations at various angles), sizes, viewing conditions (binocular and monocular), gaze strategies (fixation and free gaze) and different populations (healthy subjects, patients with left neglect and patients with right brain damage). In most studies, stronger V-H illusions accompany a symmetrical bisected configuration (IT) (Avery & Day, 1969; Finger & Spelt, 1947; Gavilán et al., 2017; Josev et al., 2011; Künnapas, 1957; Wolfe et al., 2005), original or 180°-rotated configurations (Chouinard et al., 2017; Künnapas, 1955a), smaller size configurations (Thompson & Schiffman, 1974), female performances (Fraisse & Vautrey, 1956), and viewing with two eyes (Prinzmetal & Gettleman, 1993) or fixation (Chouinard et al., 2017). Moreover, patients with left hemi-neglect and/or right brain damage were more influenced by V-H illusions than healthy participants (de Montalembert & Mamassian, 2010).

Few studies involve V-H influences of movement. V-H illusion influences on motor control included the effects of deceptive allocentric cues (Elliott et al., 2009; Foster et al., 2016; Foster et al., 2015) and the use of open-loop conditions (Elliott et al., 2009; Foster et al., 2016; Foster et al., 2015; Vishton et al., 1999). In contrast, the use of a closed-loop (Servos et al., 2000) and open-loop (Vishton et al., 1999) tasks did not always succumb to the V-H illusion.

Apparently, the lack of V-H illusory influences over a closed-loop control task (Servos et al., 2000), suggests that use of updated visual inputs can eliminate illusory influences over movement. Additional experiments on this topic are needed to support this finding, which is currently based on only one study. Conversely, the V-H illusory influences over an open-loop task did exist in several experiments (Elliott et al., 2009; Foster et al., 2016; Foster et al., 2015; Vishton et al., 1999) but not others (Vishton et al., 1999). The two known instances in which illusory influences did not exist over movement involved pantomimed grasping movements with the index finger and thumb (Vishton et al., 1999). In these two cases the subjects closed their eyes, while in most other studies visual feedback of the moving limb was available. In one experiment in which subjects also closed their eyes before moving, yet succumbed to the V-H illusion, the illusory influences were greatly attenuated to suggest an influence of allocentric cues (i.e., visual feedback of the environment) when moving toward a remembered target.

Limitations of previous research

The aforementioned studies showed controversial outcomes in which effects of various visual illusions on perceptions and/or actions differ. Although several reasons were proposed to explain the two contrary views, acknowledging the limitations of previous studies can guide future investigations.

Studies conducted on the effects of Ebbinghaus, Müller-Lyer, and Ponzo illusions on manual estimates, pointing, 2-finger natural and pantomime grasping, and effects of the V-H illusion on 2-finger natural and pantomime grasp and 3-finger pantomime grasp exist. No previous studies utilize manual estimates or pointing for the V-H illusion, yet illusory influences may exist for such movements. Delayed movement effects of other illusions can reveal strong influences on movement control, yet delayed movements do not exist for the V-H illusion, thus

are unknown. In closed-loop tasks, upper limb grasping movements were resistant to the V-H illusion; however, future studies are warranted to provide support for this one study. Gaze direction differences across visuomotor studies are unknown, yet gaze direction can influence visual perceptions (Chouinard et al., 2017) and possibly movement control. Including an eye-tracker in protocols would help determine whether fixation stability or gaze direction on a V-H illusory configuration produces stronger illusory influences on visuomotor control than viewing with free gaze.

Future studies

V-H illusions provide an opportunity to study perceptual influences on actions. However, examples of similarities and differences between perception and action exist. There is a need for more research on the different influences of the V-H illusion on perceptions and actions. A more complete understanding could potentially lead to environmental aids for movement control, like its successful use for improved toe clearance in older adults when walking upstairs (Foster et al., 2015).

Two-dimensional (2D), flat surface, point-to-point drawing movements can decrease endpoint accuracy according to a perceived increase or decrease in line segment length according to the Brentano illusion (de Grave, Franz, & Gegenfurtner, 2006). While viewing line segments with inward or outward directed arrowheads (Brentano illusion, Figure 1), people asked to move a pen tip along the flat surface and in a direction parallel to a given line segment overshot the expected line end with outward directed arrowheads and undershot the expected line end with inward directed arrowheads. Thus, participants manually overestimated and underestimated line lengths according to visual perceptions when the hand and object remained visible and movement direction paralleled the line segment in the illusion. The link between manual

estimation movements and perception in this situation may not be surprising because the straight movement distance of the pen tip from one point on the surface to another would directly represent a person's visual perceptions of line segment direction and length. Conversely, illusory effects on line length estimations disappeared when the people tried to move the pen tip along the flat surface in a direction perpendicular to the given line segment of the illusion. These data provide evidence to support that deceptive illusory influences on manual estimations of line segment lengths using point-to-point straight movements are direction dependent and potentially rule out the possible matching of movement distance to perceived length at least for illusory influences along a single dimension. Future studies could be designed to answer the question, *What effect do potentially deceptive 2D illusory influences have on reaching movements? We would hypothesize that deceptive 2D illusory influence would exist for reaching movements.*

As described above, visual illusions can affect perceptions and motions differently, for instance, people deceived by visual illusions perceptually can accurately produce motor output corresponding to actual visual illusion components correctly (Aglioti et al., 1995; Brenner & Smeets, 1996; Whitwell et al., 2018). An eye tracker has been used for investigating the change of fixation stability and gaze direction on visual perceptions. Results revealed that gaze fixation on a visual illusion produces stronger illusion than free gaze (Chouinard et al., 2017). If this possibility is confirmed for movement, further research could involve a gaze fixation rehabilitation intervention to help people with motor deficits improve their locomotion. Thus, future studies could be designed to answer the question, *Where do people look when their movements are influences by the V-H illusion? We would hypothesize that movements would be influenced when people look at the illusion rather than gazing freely.*

At the early phase of perceptuomotor control, motor planning, people are biased by illusions and during the late phase of perceptuomotor control, online control/correction, people have relatively longer time to correct or scale their hand to the physical/real size of an object (Glover & Dixon, 2001). A future study could be designed to answer, *Does performing movements slower produce fewer influences of the V-H illusion over movement? We would hypothesize that individuals' movements would be less biased by the V-H illusion when they perform the movements slower.*

CHAPTER 3. MANUAL LENGTH ESTIMATIONS CAN SIMULATE VERTICAL-HORIZONTAL ILLUSORY PERCEPTIONS DIFFERENTLY DURING VERTICALLY AND HORIZONTALLY DIRECTED REACHING MOVEMENTS: STUDY 1

INTRODUCTION

Prior to the motor execution, a person can utilize feedforward sensations from visual and proprioceptive inputs to perceive the target's size and orientation, determine movement direction and distance, and plan efficient control strategies to reach the object with precision. People show the highest endpoint accuracy when they can see the hand and target during the movement (Beaubaton & Hay, 1986) to suggest an important role of vision for such control. Allocentric sensory cues from the environment can also improve precision and accuracy of goal-directed movements for seated (Blouin et al., 1993; Gentilucci, Daprati, Gangitano, & Toni, 1997) or standing (Hondzinski & Cui, 2006) individuals. Certain grid-pattern information presented in the background can enhance accuracy of pointing movements. (Coello & Grealy, 1997; Conti & Beaubaton, 1980; Schoumans, Koenderink, & Kappers, 2000). In contrast, providing people with illusory visual information can decrease accuracy of reaching movements (Heath & Binsted, 2007). Research on the visual illusory influences on movement is interesting because the visual illusion may offer a non-invasive way to improve movement performance; increase vertical toe clearance when stepping up, for example (Elliott, Vale, Whitaker, & Buckley, 2009; Foster, Buckley, Whitaker, & Elliott, 2016; Foster, Whitaker, Scally, Buckley, & Elliott, 2015).

Some researchers reveal deceptive illusory influences on movement control. Point-to-point drawing movements on a flat surface can decrease endpoint accuracy according to a perceived long or short segment length of the Brentano illusion (de Grave, Brenner, & Smeets, 2004). While viewing the Brentano illusion (Figure 3.1), people moved a pen tip the length of

segment “a” actually moved a shorter distance than the segment length when moving in a direction parallel to the illusion. People asked to move a pen tip the length of segment “b” actually moved a longer distance than the segment length when moving in a direction parallel to the illusion. Thus, participants manually overestimated and underestimated line lengths according to visual perceptions when the hand and object remained visible and movement direction paralleled the line segment for this illusion. The link between manual estimations and perceptual judgments in this situation may not be surprising because the straight movement distance of the pen tip from one point on the surface to another would directly represent a person’s visual perceptions of line segment direction and length. Conversely, illusory effects on line length estimations disappeared when the same people tried to move the pen tip in a direction perpendicular to the given line segment of the Brentano illusion (de Grave et al., 2004). These data provide evidence to support that deceptive illusory influences on manual estimations of line segment lengths using straight point-to-point movements depend on the direction of the one-dimensional illusory aspects of this illusion.

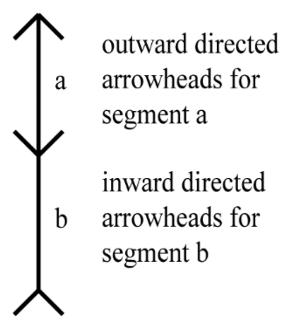

Figure 3.1. Brentano illusion in studies. With two segments (a and b) identical in length, the inward directed arrowheads correspond to perceived underestimation of the segment length (a) and outward directed arrowheads correspond to perceived overestimation of the segment length (b) (Porac, 1994).

Other researchers reveal that alterations in manual length estimations of segment lengths in the perpendicular direction exist according to 2D deceptive illusory influences of the vertical-

horizontal (V-H) illusion. The V-H illusion causes overestimation of the vertical segment length and underestimation of the horizontal segment length in a typical V-H illusion, inverted T (IT) configuration. (see Figure 3.2A) (Mamassian & de Montalembert, 2010; Masin & Vidotto, 1983; Vishton, Rea, Cutting, & Nunez, 1999; Wolfe, Maloney, & Tam, 2005). Such overestimation and underestimation are also seen in a perceptuomotor task. When asked to match the length of a given single horizontal segment presented on a computer screen, people made mouse movements in the anterior direction to draw relatively short vertical segments to complete IT configurations (Gavilán, Rivera, Guasch, Demestre, & García-Albea, 2017). When asked to match the length of a given single vertical segment on a computer screen, the same people made mouse movements to the right to draw relatively long horizontal segments also to the right to complete an IT configuration rotated 90° clockwise. The movement of the mouse matched the estimated segment length in a given direction for this perceptuomotor task. It is still unknown whether performing upper limb movements, which do not directly match the estimated segment length and/or are performed in a specific direction would produce similar illusory results on perceptuomotor control.

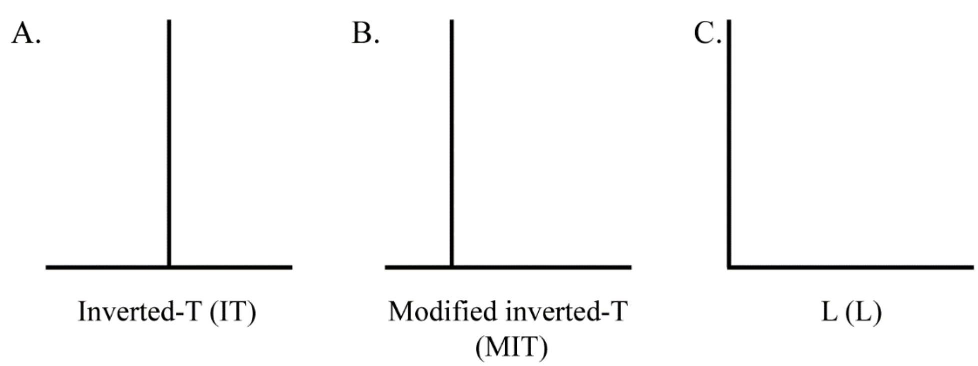

Figure 3.2. Different configurations of the V-H illusion presented to participants for perceptual trials in experiment 1: IT (A), MIT (A), and L (C). Horizontal and vertical segments for each stimulus are equal in length, yet the vertical segment appears longer to many people, especially for IT.

Two main influences of the V-H illusion are used to explain perceptual judgments of the illusion and may assist in better understanding of the perceptuomotor control of manual length estimations if biased by this illusion. The IT V-H illusion can follow bisection influences, in which the bisected segment looks shorter than the one not bisected (Künnapas, 1955). The longer vertical segment or shorter horizontal segment estimation often reduces with changes in the configuration (see for instance, Figure 3.2B for modified inverted-T (MIT) and Figure 3.2C for L) to support such influences (Mamassian & de Montalembert, 2010; Wolfe et al., 2005). Another explanation of the V-H illusion involves elliptical visual field influences, in which line segment length depends on visual field size (Künnapas, 1955). The horizontal location of the eyes in humans provides a horizontally oriented elliptical visual field. When viewing an IT configuration, the distances from the ends of the vertical segment to the boundaries of the upper and lower visual field are shorter than the distances from the ends of the horizontal segment to the right and left visual field boundaries to make the horizontal segment appear shorter. The continued existence of perceived longer vertical segments with 90° IT rotations supports the visual field influences (Charras & Lupiáñez, 2010; Renier, Bruyer, & De Volder, 2006). Including multiple configurations and rotation of these configurations would allow for greater understanding of potentially deceptive 2D V-H illusory influences on manual length estimations of segment lengths in the perpendicular direction.

In order to determine whether manual length estimations of segments in the perpendicular direction are influenced by potentially deceptive 2D illusory cues, we designed the following study. With known perceptual differences across people (Wolfe et al., 2005), we ensured study participant's perceptual judgements were deceived according to the V-H illusory influences. We chose different orientations and variations of the illusion (IT, MIT, and L configurations, Figure

3.2) to further assess potential bisection and visual field influences on performances. Using upright and rotated configurations allowed us to determine whether manual length estimations varied for vertical and horizontal directions. Using curved point-to-point reaching movements and different fingertip locations prior to movement ensured that movement distance did not directly represent final length estimations. We hypothesized that perceptuomotor control for manual length estimations of segment lengths in the perpendicular direction would be influenced by the 2D illusory cues of the V-H illusion.

METHODS

Participants

Study procedures were approved by the University's Institutional Review Board. Participants read and signed informed consent after explanation and discussion of procedures and prior to participation. Pilot data revealed medium to high effect sizes and greater than 80% power on main effects for 12 participants. Thus 12 right-handed participants (4 females; age = 23 ± 4.9 years; height = 174.7 ± 8.6 cm) recruited from Louisiana State University completed this study. Right hand dominance was determined using the Edinburgh Handedness Inventory; range 70-100 (Oldfield, 1971). Participants had no difficulty viewing targets on the computer screen within arm's length (visual acuity 20/40 or better on the Snellen eye chart assessment).

Setup

Figure 3.3 shows the experimental setup and start position. The slightly elevated computer screen tilt of 10° from horizontal helped avoid reflective interference with data collection in the perceptuomotor task. Stimuli were presented on a 27.5 x 27.5 cm computer screen with a 10.5 cm black square frame. Participants stood with feet a self-selected distance

apart, which was marked to remain constant across trials. Distance between participants and the near edge of the computer frame was 10 cm. Room lights were dimmed slightly to enhance projection of stimuli.

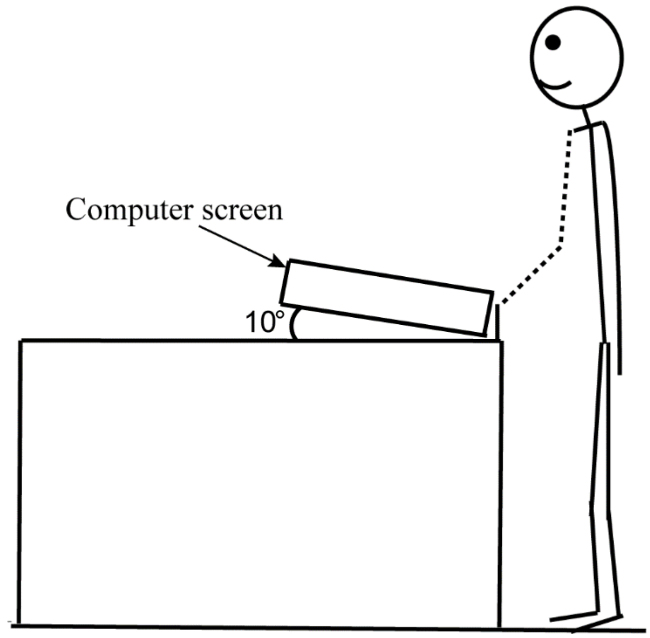

Figure 3.3. Lateral view of experiment setup in start position.

Perceptual judgment stimuli

With known perceptual differences across people (Wolfe et al., 2005), we wanted to ensure that study participant's perceptual judgements were influenced by the V-H illusion. As a reminder, people often report that the length of the vertical segment exceeds the corresponding length of the horizontal segment when segments are actually equal in length. Configurations for the perceptual task included IT, MIT, and L (Figure 3.2A-C). Stimuli involved 3-point width (1.6 mm) solid white line segments on a black background designed using Microsoft PowerPoint (Office 2010). We placed the V-H intersection at the center of the square screen. IT, MIT, and L configurations were presented upright or rotated 90° clockwise. For variety, we altered configuration baseline lengths (45 mm or 60 mm), which was the horizontal segment for upright

configurations and the vertical segment for rotated configurations. Relative lengths of the perpendicular segment included: equal to baseline; 10% increase in baseline length; 10% decrease in baseline length.

Perceptual judgment task

After viewing a configuration, participants orally reported “equal” when the segments appeared identical in length, “horizontal” when the horizontal segment appeared longer than the vertical segment, and “vertical” when the vertical segment appeared longer than the horizontal segment. Two investigators recorded participants’ responses to maintain accurate reporting. Participants were presented with three trials of each configuration (L, MIT, IT), baseline length (45 mm, 60 mm), orientation (upright, rotated), and relative length (equal, 10% increase in baseline length, 10% decrease in baseline length) to obtain 36 trials for each configuration. A total of 108 trials were presented in a mixed order, while ensuring no more than two of the same trial were presented in a row. Three breaks were given to each participant for as long as requested. Task duration lasted less than 25 minutes.

Perceptuomotor stimuli

Perceptuomotor stimuli included versions of IT, MIT, and L configurations with either a 45 mm or 60 mm baseline length, for variety. Similar to the perceptual judgment task, V-H intersection of all configurations were set at the center of the square computer screen and stimuli involved 3-point width (projected line width = 1.6 mm) solid white line segments on a black background designed using Microsoft PowerPoint (Office 2010). Horizontally (Figure 3.4A) and vertically (Figure 3.4B) oriented baselines intersected with a perpendicular segment (length = 137.5 mm) which extended to the edge of the computer screen. Therefore, configurations were

set upright or oriented 90° to the right (rotated) so that the participants produced vertically or horizontally directed movements, respectively.

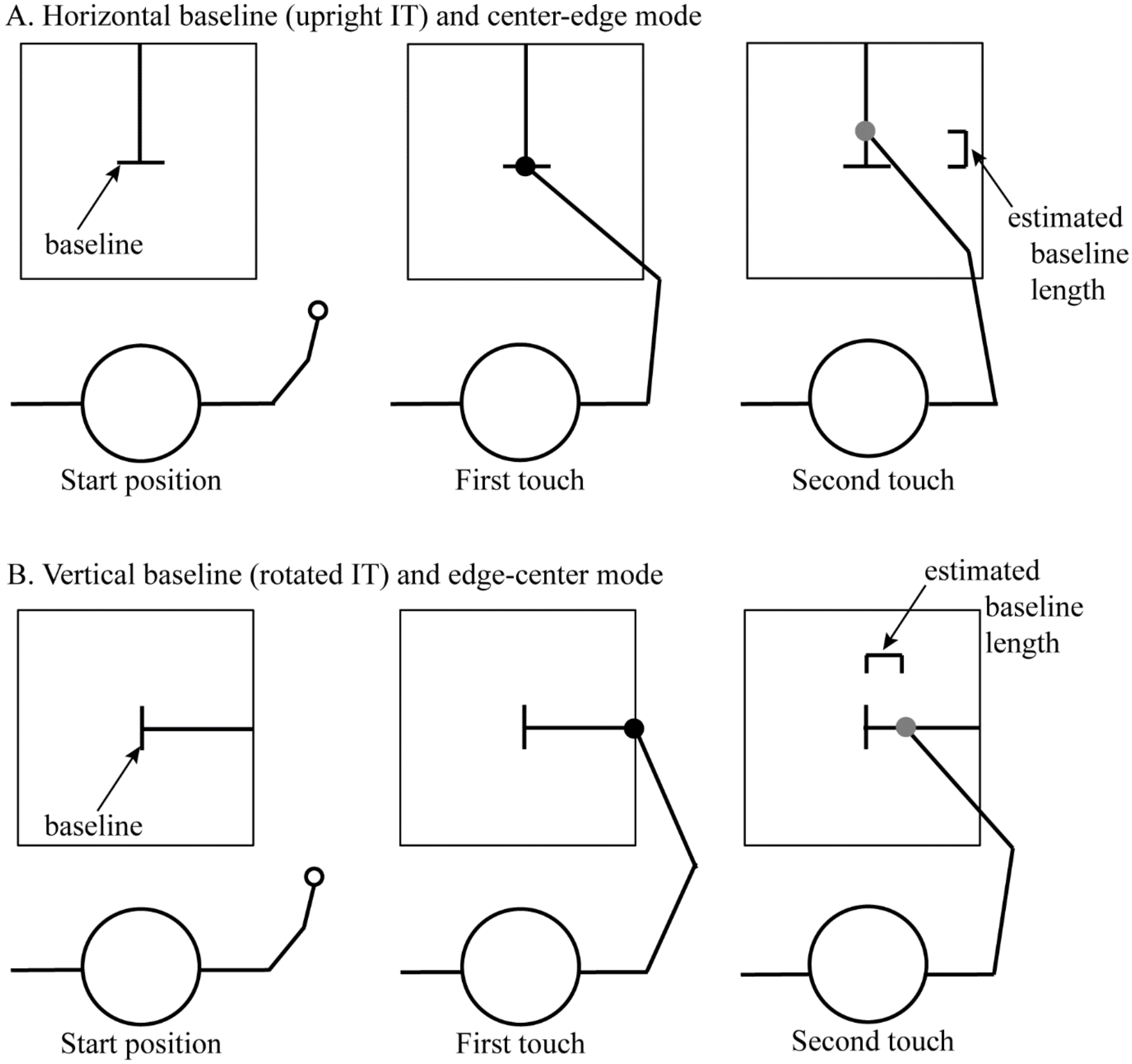

Figure 3.4. Experimental procedures. (A) Upright IT configuration with a horizontal baseline for vertically directed movements in the center-edge mode and (B) rotated IT configuration with a vertical baseline for horizontally directed movements in the edge-center mode are presented from an overhead view. Left panels represent start position, while middle and right panels represent first and second touches, respectively. Distance between first and second touches represent the estimated baseline lengths.

Perceptuomotor task

Participants began in the start position (Figure 3.3) with their right fingertip on the start location, 7.5 cm to the right of and 6 cm anterior to the front edge of the outside frame (left

panels, Figure 3.4, frame not shown). Two movement modes, center-edge mode (Figure 3.4A) and edge-center mode (Figure 3.4B), were performed in this study. In each case, participants viewed a configuration, then were asked to manually estimate the length of the baseline segment in the perpendicular direction.

In the center-edge mode, after viewing a configuration, participants used their right index finger to touch the configuration at the intersection of the baseline and perpendicular segments, pause for 1 s, then lift the finger and touch the screen again at a distance on the perpendicular segment, so that the length from first touch to second touch matched the length of the baseline (see “estimated baseline length” in right panel, Figure 3.4A). A “relax” command signaled participants to move back to the start position and prepare for the next trial. In control trials, participants touched the endpoints of a horizontal or vertical segment of 45 mm or 60 mm using the same touch, pause, lift and touch technique. Note that the first touch always corresponded to the lower end of a vertical segment or to the left end of a horizontal segment. Therefore, the first touch of participants was always at the center of the computer screen and the second touch was closer to its edge.

In the edge-center mode, participants applied the same touch, pause, lift and touch movement pattern. However, they moved from the start position to touch the intersection of the long segment of the configuration with the square screen edge (see first touch, middle panel, Figure 3.4B), then moved toward the screen center to a final position, so that the distance between segment intersections and final position equaled the baseline length (see second touch and “estimated baseline length”, right panel, Figure 3.4B). Again, a “relax” command signaled participants to move back to the start position and prepare for the next trial. In a control trial, a single horizontal or vertical segment of 45 mm or 60 mm was presented. Participants touched the

location represented by the extended segment intersection with the screen edge, actually marked for location of first touch (middle panel, Figure 3.4B), paused, then lifted the finger and touched the top or right end of the vertical or horizontal segment, correspondingly.

The perceptuomotor task involved 12 trials of each condition and included: 45 mm L horizontal baseline (1); 45 mm L vertical baseline (2); 45 mm MIT horizontal baseline (3); 45 mm MIT vertical baseline (4); 45 mm IT horizontal baseline (5); 45 mm IT vertical baseline (6); and another six similar conditions for the 60 mm baseline for each movement mode. We alternated the 144 trials within each movement mode so that no more than two of the same trial were presented in a row. Four control trials were performed for each movement direction, baseline length, and movement mode. Half the participants completed the center-edge mode first and the edge-center mode second, while the other half completed the edge-center mode first and the center-edge mode second.

Participants performed several practice trials to become familiar with the task. Breaks were given every 2 minutes for as long as requested, which was less than 2 minutes. They took about 90 minutes to complete experimental and control trials.

Data collection and analysis

Perceptual judgment task

Two investigators recorded oral responses for accuracy check. To calculate the correct and incorrect percentage, counted the number of trials of correct and incorrect responses that corresponded to bisection and visual field influences, and divided these numbers by total trial number.

Perceptuomotor task

To track the fingertip displacements, a 4-camera Qualisys motion capture system (Qualisys Medical AB, SE) was used (60 Hz), with a 2 cm diameter marker was placed on the fingertip of the dominant hand. Kinematic data of the fingertip marker were lowpass filtered using a Butterworth second order filter with 6 Hz cutoff frequency and differentiated with respect to time to obtain velocity profiles. Start and end of movement were determined when velocity was maintained below 5% of peak velocity for ≥ 100 ms before and after movement, respectively using a Matlab program. For the center-edge mode, length estimations were determined by subtracting fingertip start from fingertip end. To allow for direct comparisons between movement modes, a length estimation for each trial in the edge-center mode was calculated relative to the configuration intersection as 137.5 – the difference between fingertip start and end. Next, each trial length estimation was divided by the mean control length estimation for each size, configuration, movement direction, movement mode, and participant to determine a length estimation ratio normalized by size. Mean length estimation ratio (ratio) was calculated by averaging the normalized displacement ratios for each configuration, movement direction, movement mode, and participant. Mean length estimation ratio are normally distributed assessed using the Shapiro-Wilk W test. Effects of configuration (L, MIT, IT), movement direction (vertical, horizontal), and movement mode (center-edge, edge-center) on ratio were analyzed with repeated measures ANOVAs (Tukey's post-hoc tests, $\alpha = .05$). Effect size (ES) corresponding to partial eta squared represents the strength of relationships for significant outcomes. Strength of ES were considered small ≤ .25 and large ≥ .40 with medium between .25 and .40 (Cohen, 1969).

RESULTS

Perception judgment task

Results showed that participants in this study revealed perceptual judgments that were influenced by the V-H illusion; however, results varied across people. For upright configurations, participants often perceived a longer vertical segment regardless of configuration when the vertical segment was actually longer and provided the most correct responses in this instance. Some illusory responses for IT (mean: 80%, range: 58-100%) exceeded those for MIT (mean: 56%, range: 17-100%) and L (mean: 51%, range: 0-100%), which were similar. For rotated configurations, participants provided the most correct responses when the segments were equal for IT and when the vertical segment was actually longer than the horizontal segment for MIT and L. Illusory responses for rotated IT (mean: 48%, range: 33-67%), MIT (mean: 51%, range: 39-67%), and L (mean: 60%, range: 42-75%) were fairly close, especially between rotated IT and MIT. These data indicate that participants in this study revealed illusory perceptual influences of the V-H illusion.

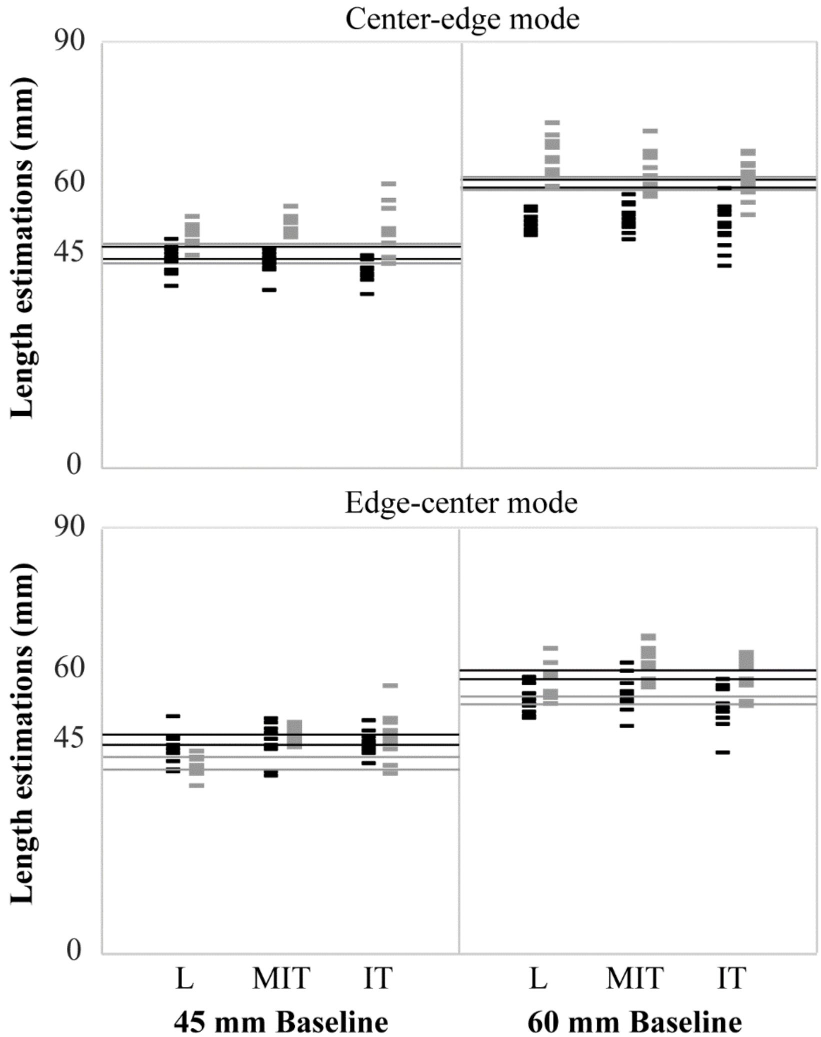

Figure 3.5. Raw data of manual length estimations during vertically (black) and horizontally (gray) directed movements of the 45 mm (left panels) and 60 mm (right panels) baseline lengths for each trial of one participant are shown in the center-edge mode (top panels) and edge center mode (bottom panels). Configurations (L; MIT—modified inverted T; IT—inverted T) are presented on the x-axis. Horizontal lines represent the length estimations for control trials during the horizontally (gray) and vertically (black) directed movements.

Perceptuomotor task

The raw data of manual length estimations for reaching movements of one participant are shown for the center-edge mode (top panels, Figure 3.5) and the edge-center mode (bottom panels, Figure 3.5). This participant often overestimated the perpendicular baseline lengths for

horizontally directed movements and underestimated the perpendicular baseline lengths for vertically directed movements. This performance was similar to the average across participants in the center-edge mode but not in the edge-center mode (see Figure 3.6). Note that ratio values which exceeded 1 indicated an overestimation of the estimated perpendicular baseline length, while ratio values less than 1 indicated an underestimation of the estimated perpendicular baseline length.

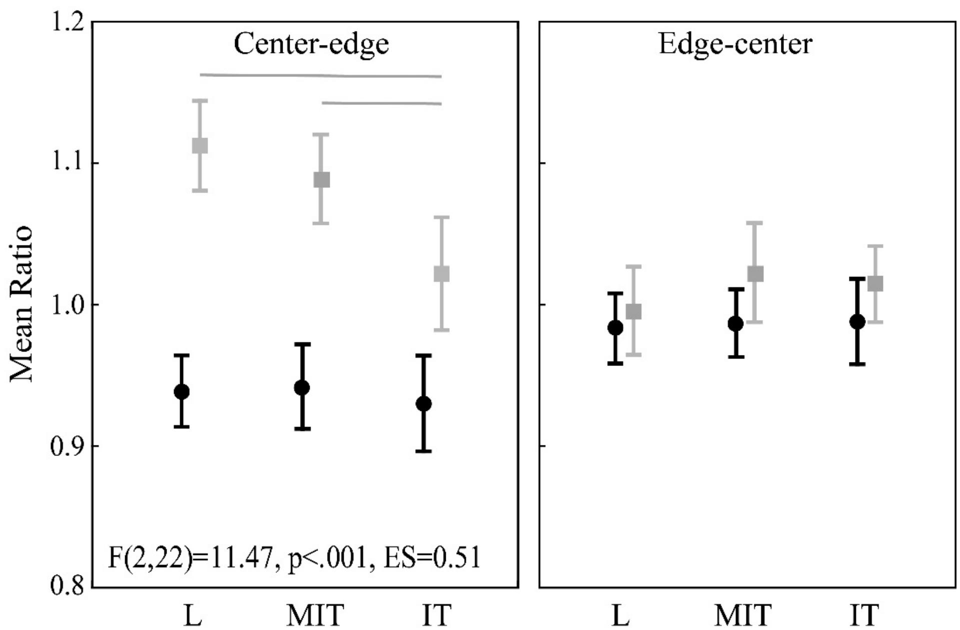

Figure 3.6. Mean ratios associated with manual length estimations for movement direction (vertical in black; horizontal in gray) x configuration (L; MIT—modified inverted T; IT—inverted T) x movement mode (center-edge, left panel; edge-center, right panel) interaction are shown. Significant differences between configuration means within a movement mode are identified at the ends of horizontal gray line segments for horizontally directed movements.

Results which revealed a significant main effect of movement direction on ratio ($F(1,11) = 9.331$, $p < .05$, $ES = .46$) indicated that the ratio during horizontally directed movements (1.04, an overestimation of baseline length) exceeded the ratio during vertically directed movements (0.96, an underestimation of baseline length). Movement mode and configuration did not produce significant effects on ratio.

Several significant two-way interactions existed for ratio. The significant configuration x movement direction interaction on ratio ($F(2,22) = 6.16$, $p < .01$, $ES = .36$) denoted a larger ratio for L (1.05) and MIT (1.06) than for IT (1.02) only during horizontally directed movements. The significant movement direction x movement mode interaction ($F(1,11) = 5.34$, $p < .05$, $ES = .33$) signified a smaller ratio during vertically directed movements (0.94) than horizontally directed movements (1.07) only in the center-edge mode. The significant configuration x movement mode interaction ($F(2,22) = 8.09$, $p < .01$, $ES = .42$) indicated that ratio for L in the center-edge mode (1.03) exceeded ratio for L in the edge-center mode (0.99) and that ratio of L (1.03) and MIT (1.02) significantly exceeded that for IT (0.98) only in the center-edge mode.

The significant 3-way interaction of configuration x movement direction x movement mode on ratio revealed the main results of this study (Figure 3.6; observed power = .98). Specifically, ratios for L and MIT exceeded IT ratio only during horizontally directed movements in the center-edge mode (left panel, Figure 3.6). The figure also reveals that ratio for each configuration in the edge-center mode and during horizontally directed movements of IT in the center-edge mode were close to 1, suggesting similar performance to control conditions for these configuration and movement mode combinations. In addition, ratios remained similar between center-edge and edge-center modes only for IT when movements were directed horizontally; otherwise ratios during horizontally directed movements in the center-edge mode exceeded those in the edge-center mode, while the ratios during vertically directed movements in the edge-center mode exceeded those in the center-edge mode. These results suggest differences between movement modes for most configuration and movement direction combinations.

DISCUSSION

The primary aim of this study was to investigate whether manual length estimations of baselines in the perpendicular direction using reaching movements were influenced by potentially deceptive 2D illusory cues. We determined our participants visual perceptions were influenced by the V-H illusion and briefly discuss their deceived perceptual responses with findings in other work. We then address that perceptuomotor control for manual length estimations of baselines in its perpendicular direction also succumbed to V-H illusory influences and discuss how the evidence improves our understanding of the sensorimotor control.

Perceptual judgment task

We conducted perceptual experiments involving the three configurations in Figure 3.2A-C with the perpendicular segment length greater than, equal to, or less than the baseline length. For upright configurations, the vertical segment of each configuration frequently appeared longer than its actual length to indicate V-H illusory influences in our participants for this orientation. Participants also reported illusory responses for IT most often and fewer for L (Künnapas, 1955; Renier et al., 2006) and MIT (Charras & Lupiáñez, 2010; Wolfe et al., 2005) to support the idea that V-H illusory effects on perception followed visual field and bisection influences for upright IT.

In contrast to the 80% illusory influences for upright IT, illusory effects on perceptual judgments decreased to 48% when presenting participants with rotated IT. These reductions on perceptual judgments with rotation of IT (Charras & Lupiáñez, 2010; Renier et al., 2006) might be expected because a conflict exists between illusory influences in which those of visual field oppose those for bisection (Finger & Spelt, 1947). Although individualized weighting of illusory influences varied across participants to show the existence of idiosyncratic differences in

perceptual judgments (Wolfe et al., 2005), most participants in the present study also revealed visual field and bisection influences on perceptual judgments of rotated IT.

Perceptuomotor Task

The significant interaction among configuration, movement direction and movement mode revealed V-H illusory effects on perceptuomotor control for one movement mode of the given task. In the center-edge mode, manual length estimations of the baselines during vertically directed reaching movements were often smaller than actual baseline lengths. Furthermore, manual length estimations of the baselines during horizontally directed reaching movements were often greater than actual baseline lengths and greater than vertically directed movements. Similar results existed when people used a mouse to draw an estimated length of a single perpendicular segment to produce an L or IT (Gavilán et al., 2017). Using a keyboard or knob to adjust the length of a horizontal or vertical segment of an L (Künnapas, 1957a; Künnapas, 1957; Künnapas, 1957b; Richter, Wennberg, & Raudsepp, 2007) or non-connecting segments (Prinzmetal & Gettleman, 1993) to match the corresponding perpendicular length also produced similar results to those of our study. In each case people either underestimated horizontal baseline lengths and/or overestimated vertical baseline lengths. Thus, using curved reaching movements in the present study, in which reach distance did not directly match estimated baseline lengths, did not seem to matter as on overage illusory influences remained for this perceptuomotor task in the center-edge mode.

It appears that perceptuomotor control matched perceptual judgments for the center-edge mode. The observed decrease in vertical displacement associated with ratios smaller than 1, could result if participants' estimations matched a perceived shorter horizontal baseline. Likewise, the increase in horizontal displacement associated with ratios greater than 1, could

result if participants' estimations matched a perceived longer vertical baseline. These results were observed during vertically directed movements for upright configurations and for rotated MIT and L during horizontally directed movements. The present results support the existence of V-H illusory perceptions corresponding to relatively longer vertical segments than horizontal segments for upright MIT (Wolfe et al., 2005) and upright and rotated L (de Montalembert & Mamassian, 2010) and support the use of visual field influences (Künnapas, 1957a; Künnapas, 1957; Künnapas, 1957b; Prinzmetal & Gettleman, 1993) on perceptuomotor control. These perceptual influences produced a relatively strong impact on manual estimations of baseline lengths using reaching movements regardless of the symmetrical frame used, which was previously shown to reduce the perceptual effect of an elliptical visual field (Gavilán et al., 2017; Houck, Mefferd, & Greenstein, 1972; Künnapas, 1959). The movement direction influences observed in the present study emphasize the importance of human eye location associated with visual field on perceptuomotor control.

Having visual field and bisection influences in the same direction during vertically directed movement produces no perceptual conflict for IT, thus participants frequently underestimated baseline lengths when performing vertically directed movements for this configuration (7% length underestimations of the horizontal segment on average). These results support others who reported 7% (Finger & Spelt, 1947) and 17% (Gavilán et al., 2017) length underestimations of the horizontal segment of IT. In contrast, having perceptual influences which compete may make the use of each influence more important, thus imperative for controlling horizontal movements. Results provided evidence for the existence of competing influences on control that imitated those for perceptual judgments. In this case, bisection influences competed with visual field influences for the symmetrical configuration of IT (Gavilán et al., 2017) and

cancelled each other to reveal ratios closer to 1 than MIT and L (see left panel, Figure 3.6). In fact, participants slightly overestimated vertical baseline lengths by 2% for IT when producing horizontal movements; however, underestimations also existed. Participants also overestimated vertical baseline lengths by 3% when adjusting the horizontal segment length by pulling on one end to hide part of the segment behind a display board (Finger & Spelt, 1947) and underestimated vertical baseline lengths by 3% when drawing horizontal segment lengths (Gavilán et al., 2017). These data support the application of multiple illusory constructs to explain manual length estimations of baselines in the perpendicular direction for this V-H illusory task, during horizontally and vertically directed movements.

Except for horizontally directed movements for IT, significant differences existed between movement modes within the current study (see Figure 3.6). During vertically directed movements, undershooting manual length estimations of baselines in the center-edge mode differed from manual length estimations of baselines in the edge-center mode, the latter of which approximated 1. During horizontally directed movements, overshooting manual length estimations of baselines for MIT and L in the center-edge mode differed from the corresponding manual length estimations of baselines in the edge-center mode, again, the latter of which approximated 1. Moreover, unlike the movement direction differences observed for the center-edge mode across participants, movement direction differences where not consistent across participants for the edge-center mode.

Task requirements offer plausible explanations for the differences observed between center-edge and edge-center modes. Finger location for first touch in the center-edge mode at the V-H intersection blocks portions of the vertical and horizontal segments, while finger location at first touch in the edge-center mode does not block these segments and may allow participants

greater configuration viewing time during first touch to second touch. Allowing greater viewing time can reduce the effects of the V-H illusion on perceptual judgments but this usually requires relatively long viewing times (i.e., 20 seconds or greater, Brosvic, Walker, Perry, Degnan, & Dihoff, 1997) which did not occur in this study. A more likely explanation for the differences between movement modes links to gaze direction. Gaze directed toward the intersection of the V-H illusion produces greater illusory influences on perception than free gaze (Chouinard, Peel, & Landry, 2017). Requiring first touch at the intersection of the configurations in the center-edge mode would encourage gaze direction toward the intersection to ensure correct finger placement. Requiring first touch at the frame in the edge-center mode would encourage gaze direction away from the configuration to ensure correct finger placement. Subsequently, participants would need larger and possibly additional gaze shifts, as in a free gaze condition, to view the configuration prior to movement in the edge-center mode compared to the center-edge mode. This could result in greater illusory influences on perceptuomotor control in the center-edge mode than the edge-center mode, like those observed in our study.

LIMITATIONS

The major limitation of this study is the reliance on indirect evidence for differences between movement modes. We proposed use of a gaze direction strategy to explain differences between movement modes. Although it is reasonable to assume gaze direction to ensure correct fingertip placement during first touch in this study, use of an eye tracker could verify gaze direction control during task performances.

CONCLUSION

Manual length estimations of baselines in the perpendicular direction using curved point-to-point reaches corresponded to different aspects of visual perceptual influences. V-H illusory

effects of configurations differed by movement direction to show support for varied use of visual field and bisection effects on manual length estimations in the center-edge mode. Evidence supported that conflicting visual field and bisection influences on manual length estimations existed during horizontally directed movements associated with rotated IT in this mode. Producing edge-center movements probably encouraged greater alterations in gaze shifts during performances, apparently limiting V-H illusory influences on perceptuomotor control. Data suggest that exploitation of simple deceptive influences of the V-H illusion can alter upper limb sensorimotor control in most people under certain methodological constraints.

CHAPTER 4. GAZE LOCATION CHANGES THE VERTICAL-HORIZONTAL ILLUSORY EFFECTS ON MANUAL SIZE ESTIMATIONS: STUDY 2

INTRODUCTION

Coordinated goal-directed reaching and pointing movements involve the integration of sensory and motor systems (Archambault, Ferrari-Toniolo, Caminiti, & Battaglia-Mayer, 2015). People receive and process feedforward and feedback sensory information when moving the hand toward a target (Beaubaton & Hay, 1986). Prior to the motor execution, a person can utilize visual and proprioceptive inputs to perceive the target's size and orientation, determine movement direction and distance, and plan efficient control strategies to reach the object with precision.

Allocentric sensory cues from the environment can also contribute to precision and accuracy of goal-directed movements (Blouin et al., 1993; Gentilucci, Daprati, Gangitano, & Toni, 1997; Hondzinski & Cui, 2006). Use of a structured visual background, such as a grid-pattern to reduce endpoint errors, can enhance accuracy of pointing (Coello & Grealy, 1997; Conti & Beaubaton, 1980; Schoumans, Koenderink, & Kappers, 2000). In contrast, providing people with deceptive allocentric visual cues can decrease reaching accuracy (Heath & Binsted, 2007). Exploitation of deceptive visual influences on movement is appealing because it offers a non-invasive way to alter sensorimotor control and potentially modify movement in a positive manner; enhance toe clearance when stepping up, for example (Elliott, Vale, Whitaker, & Buckley, 2009; Foster, Buckley, Whitaker, & Elliott, 2016; Foster, Whitaker, Scally, Buckley, & Elliott, 2015). The overall goal of the present study was to determine whether the alteration of certain performance parameters can enhance the use of deceptive visual influences over movement control for potential use in future applications.

Influences of deceptive allocentric visual cues on movement control can provide insight into the use of two different visual systems. The “two-visual-systems” hypothesis indicates a dissociation of visual pathways for perception and action (Goodale & Milner, 1992; Milner & Goodale, 1995). Some studies on deceptive visual cues using visual illusions support this dissociation by showing differences between perceptual judgments and actual movements (Aglioti, DeSouza, & Goodale, 1995; Haffenden & Goodale, 1998; Ganel, Tanzer, & Goodale, 2008) so that people’s perceptual reports can follow visual illusory influences without biasing action (Bartelt & Darling, 2002; Ganel et al., 2008; Goodale, 2014; Haffenden & Goodale, 1998; Westwood, Chapman, & Roy, 2000). However, other reports reveal visual illusory influences over a person’s perception and action similarly (Elliott et al., 2009; Foster et al., 2016; Foster et al., 2015), contradicting the two-visual-systems hypothesis (Franz & Gegenfurtner, 2008; Franz, Gegenfurtner, Bülthoff, & Fahle, 2000; Kopiske, Bruno, Hesse, Schenk, & Franz, 2016, 2017; Mendoza, Hansen, Glazebrook, Keetch, & Elliott, 2005). Inconsistent effects of visual illusion on perception and action are still under debate.

To dispute the dissociation between visual perception and action when presented with illusory visual cues, some researchers reveal illusory influences on movement control. Two-dimensional (2D), flat surface, point-to-point drawing movements can decrease endpoint accuracy according to a perceived increase or decrease in line segment length of the Brentano illusion (de Grave, Brenner, & Smeets, 2004). While viewing the Brentano illusion (Figure 4.1A), people asked to move a pen tip the length of segment “a” actually moved a shorter distance than the segment length when moving in a direction parallel to the illusion. People asked to move a pen tip the length of segment “b” actually moved a longer distance than the segment length when moving in a direction parallel to the illusion. Thus, participants manually

overestimated and underestimated line lengths according to visual perceptions when the hand and object remained visible and movement direction paralleled the line segment of this illusion. The link between manual estimations and perceptual judgments in this situation may not be surprising because the straight movement distance of the pen tip from one point on the surface to another would directly represent a person’s visual perceptions of line segment direction and length. Moving the hand off the 2D surface during curved pointing in a touch-lift-touch pattern, in which movement distance does not directly match visual perceptions of segment length, may not produce the same outcomes.

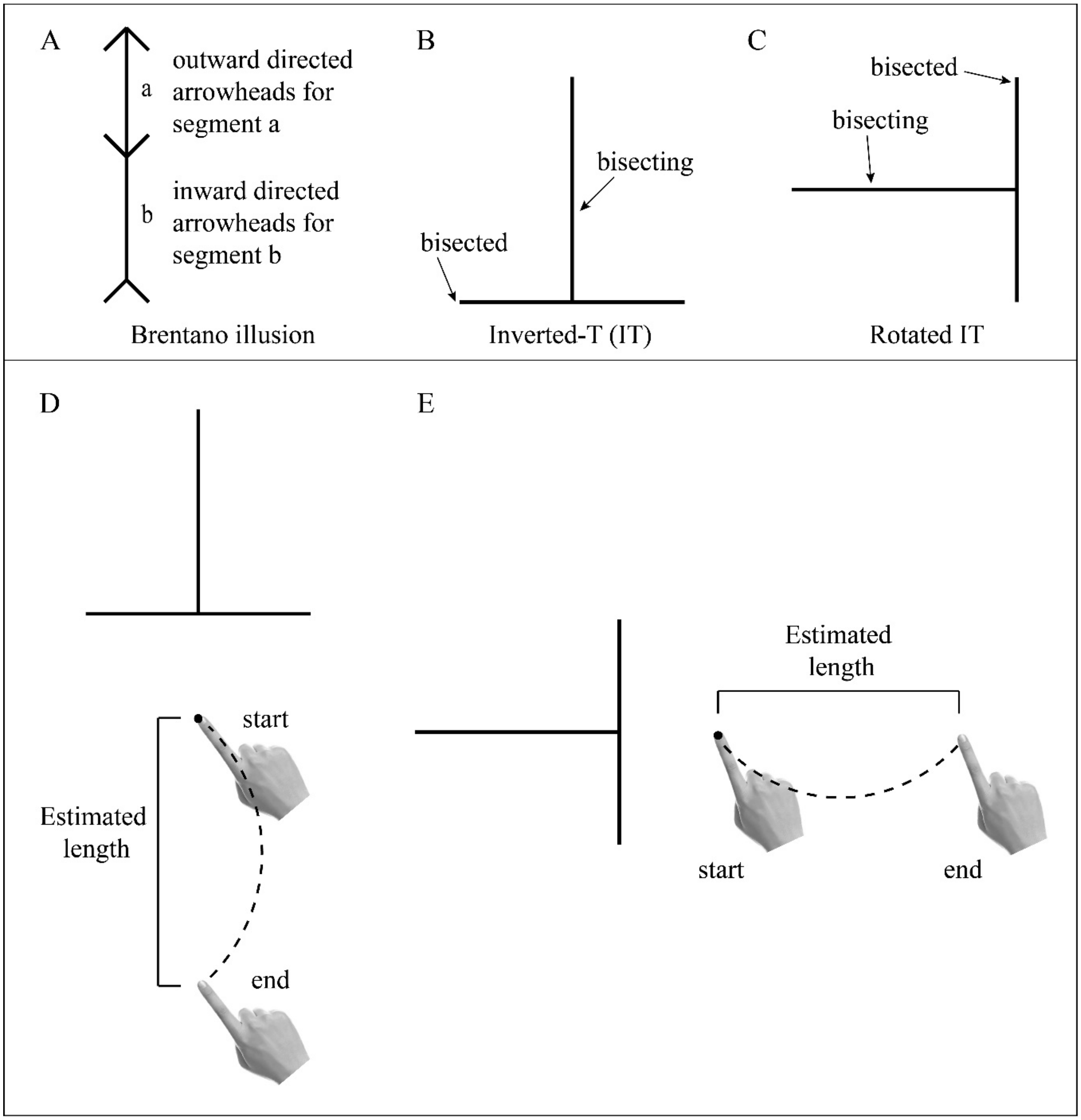

Figure 4.1. Demonstration of illusions and experimental procedures. Brentano illusion (A); The inverted-T (IT) of the V-H illusion (B); Rotated IT of the V-H illusion (C); Stimuli and movement for upright (D) and rotated (E) configurations. A start dot was always presented. Participants produced pointing movements by lifting their finger off the screen and placing it back on the screen at an end location to estimate the length of the corresponding bisecting segment.

Manual estimations of segment lengths can also be biased according to deceptive influences of the vertical-horizontal (V-H) illusion. When viewing an inverted-T (IT) configuration (see Figure 4.1B), most people often perceive that a vertical segment appears

longer than a horizontal segment of equal length or that a horizontal segment appears shorter than a vertical segment of equal length (Mamassian & de Montalembert, 2010; Masin & Vidotto, 1983; Vishton, Rea, Cutting, & Nunez, 1999; Wolfe, Maloney, & Tam, 2005). When performing a perceptuomotor task involving segment length estimations, people can underestimate the horizontal segment length and overestimate the vertical segment length according to the V-H illusion. For example, when asked to match the length of a given single horizontal segment presented on a computer screen, people made mouse movements in the anterior direction to draw relatively short vertical segments to complete IT configurations (Gavilán, Rivera, Guasch, Demestre, & García-Albea, 2017). When asked to match the length of a given single vertical segment on a computer screen, the same people made mouse movements to the right to draw relatively long horizontal segments also to the right to complete an IT configuration rotated 90° clockwise. The movement of the mouse allowed for online adjustments and visual feedback of the seen line, which matched the estimated segment length according to the V-H illusion for this perceptuomotor task. People in this study followed bisection influences, in which the bisected segment looks shorter than the one not bisected (Künnapas, 1955; Mamassian & de Montalembert, 2010; Wolfe et al., 2005). See examples of an IT and a rotated IT in Figure 1b and 1c, respectively. It is unclear whether performing upper limb movements, which do not directly match the estimated segment length without multiple online adjustments, would produce similar illusory results on perceptuomotor control.

Some factors blamed for illusory effects on perception and action in the cases just described and not others include illusion size (Bruno, Bernardis, & Gentilucci, 2008; Kopiske et al., 2017), illusion type (Bruno et al., 2008; Thompson & Schiffman, 1974), and experimental procedures (Bruno et al., 2008; Kopiske et al., 2017). One experimental procedure that has

influenced perceptual responses and may influence motor responses involves the use of gaze fixation. In one study, gaze fixation instability positively correlated with the perceptual strength of a visual illusion (Murakami, Kitaoka, & Ashida, 2006). These results seem to contradict results of another study that revealed the more stable a person's retinal image, the stronger the perceptual illusion (Chouinard, Peel, & Landry, 2017). In this latter study, people looking at the intersection of V-H illusion had a greater illusory impact on perception than looking freely. With variable alterations in gaze fixation corresponding to greater illusory perceptual influences, it seems reasonable to pose the influence of gaze direction on perceptual illusory influences, rather than just fixation. Therefore, the primary aim of this study was to determine the influence of gaze direction on perception and action for the V-H illusion.

In order to determine whether a dissociation between perception and action exists for the V-H illusion, we designed a study involving perceptual judgments and manual length estimations of the illusion. Altering participant's gaze direction allowed us to assess whether gaze direction known to influence perception also influenced movement. Using upright IT and rotated IT configurations, allowed us to determine whether manual length estimations varied for downward and rightward directions according to illusory perceptions, known to be strongest for the upright configuration (Charras & Lupiáñez, 2010; Cormack & Cormack, 1974; Finger & Spelt, 1947; Gavilán et al., 2017; Künnapas, 1955; Renier, Bruyer, & De Volder, 2006; Thompson & Schiffman, 1974; Wolfe et al., 2005). Using curved pointing movements prior to movement ensured that movement distance did not directly represent perceptual length estimations. Assuming an association between illusory influences over perception and action, we hypothesized that perceptuomotor control for manual estimations of the bisecting segment length

would be longer for upright than rotated configurations and longer when people fixated their gaze on the segment intersection of the V-H illusion than when gaze was directed freely.

METHODS

Participants

Study procedures were approved by the University's Institutional Review Board. Participants read and signed informed consent after explanation and discussion of procedures and prior to participation. Twelve right-handed college students (8 females; mean age ± 1 SD = 21.4 ± 1.1 years) recruited from Louisiana State University completed this study. Right hand dominance was determined using the Edinburgh Handedness Inventory; range 60-100 (Oldfield, 1971). Participants had no difficulty viewing targets on the computer screen within arm's length (visual acuity 20/40 or better on the Snellen eye chart assessment).

Setup

Participants sat in front a vertically oriented 23-inch computer screen with a resolution of 1680 x 1050 pixels. The computer screen was stabilized on a table in a frontoparallel plane such that the participant's eye level was at the height of the screen center. Participants' viewing distance was approximately 80% of their arm length (mean viewing distance ± 1 SD = 54.4 cm ± 3.7 cm; mean maximum visual angle of the illusion = 5.2°). Room lights were dimmed slightly to enhance projection of stimuli.

Visual stimuli

As a reminder, people often report that the length of the bisecting segment exceeds the corresponding length of the bisected segment when segments of the V-H illusion are actually equal in length. Configurations included an inverted-T configuration in upright (Figure 4.1B) or

rotated 90° counterclockwise (Figure 4.1C) orientations. For each configuration, the bisecting segment of 40.5 mm/49.5 mm was 10% shorter/longer than the bisected segment of 45 mm. We only included a long bisecting segment for variation. Thus, analyses were limited to short length trials due to the overlap between correct and illusory perceptual responses for the long length. The segment intersection of all configurations was set at the center of a computer screen and at each participant's eye level. A black dot with a diameter of 2 mm was used as start position and was presented 2 cm below the intersection for upright configurations (Figure 4.1D) and 2 cm right of the intersection for rotated configurations (Figure 4.1E). For control trials, the bisecting and bisected segments were equal in length and a second black dot representing the end position was provided at 40.5 mm or 49.5 mm distances for short and long lengths, respectively. Stimuli were black line segments (width = 3 mm) on a gray background designed using PsychoPy (Peirce 2007).

Perceptual judgments and perceptuomotor task

Participants were presented with one configuration at a time. Upon stimulus presentation, participants moved their right index fingertip to the black dot (see start position in Figure 1d and 1e), while establishing gaze direction, as required (see below). Once positioned, participants orally reported "equal" when the segments appeared identical in length, "horizontal" when the horizontal segment appeared longer than the vertical segment, and "vertical" when the vertical segment appeared longer than the horizontal segment. Two investigators recorded participants' perceptual responses to maintain accurate reporting.

With no expected disturbance of movement speed on accuracy (de Grave et al., 2004), participants were instructed to initiate a comfortably paced, single downward movement for upright configurations and rightward movement for rotated configurations. While maintaining

the appropriate gaze direction, participants lifted the index fingertip off the screen and moved it to a point on the screen, so that the point-to-point displacement equaled the length of the bisecting segment. An investigator gave a “relax” command which signaled participants to move their hand back to a rest position in front of the computer screen on the table and prepare for the next trial. For a control trial, participants were asked to lift and move the index fingertip to the second dot using a comfortably paced, single movement.

Participants performed perceptual judgments and manual length estimations under three different gaze conditions. In the free gaze condition, they looked wherever they preferred. In the center fixation condition, they fixated on the intersection of the vertical and horizontal segments, thus gaze was directed only toward the configuration. In the finger fixation condition, they fixated on the fingertip in start position and the space between start and end locations, thus gaze was directed only toward the movement space. Participants always performed the free gaze condition first, while order of center and finger fixation conditions alternated across participants.

The task involved 10 trials for each gaze condition (free gaze, center fixation, finger fixation), configuration orientation (upright, rotated), and length (short, long). We pseudorandomized the 40 trials within each gaze condition so that no more than two of the same trial were presented in a row. Five control trials for each configuration orientation and length were performed after 40 experimental trials in the free gaze condition to be used in analyses. Trial order was completed in PsychoPy before the experiment started.

Participants performed several practice trials to become familiar with the task. Breaks were given every 2 minutes for as long as requested, which was less than 2 minutes. They took about 70 minutes to complete this experiment.

Data collection and analyses

Perceptual judgments

Remember, without the ability to separate correct and illusory responses for the long lengths, analyses were limited to short length trials only. For the perceptual responses, we counted the number of experimental trials that the participants judged as vertical, equal, or horizontal. Dividing these numbers by total trial number within a gaze condition, configuration orientation, and participant revealed corresponding percentages for correct and incorrect, illusory responses.

Perceptuomotor task

A 60 Hz binocular Mobile Eye Tracker (SMI, Teltow, Germany) was used to ensure that gaze was directed appropriately for each trial. Online inspection of point of gaze on each participant's viewing field video during data collection allowed us to remove and repeat trials involving obvious deviations in gaze for center and finger fixation conditions. We ensured intersection fixation of gaze for center fixation trials. For finger fixation trials, we ensured fingertip fixation prior to the movement initiation, and fixation on the fingertip or in the movement space between start and end of movement. Offline analyses, involving frame-by-frame inspection of recorded video using B-Gaze software (SMI, Teltow, Germany), ensured the removal of trials with inappropriate gaze deviations not identified online. Frame-by-frame analyses of recorded video for free gaze experimental trials also allowed us to determine the time participants spent viewing the configuration, start dot (which includes finger), movement space, or elsewhere before and during movement. These viewing time data allowed us to determine the common viewing strategies used by participants when they were free to choose where they looked.

For the perceptuomotor task, a 2 cm diameter marker was placed on the index fingertip of the right dominant hand and recorded at 60 Hz with a 4-camera Qualisys system (Qualisys Medical AB, SE). Position data of the fingertip marker were lowpass filtered using a Butterworth 2nd order filter with 6 Hz cutoff frequency and differentiated with respect to time to obtain velocity profiles using a customized program in Matlab (MathWorks, Natick, USA). Start and end of movement were determined when velocity was maintained below 5% of peak velocity for ≥ 100 ms before and after movement, respectively, similar to others (Adamovich, Berkinblit, Hening, Sage, & Poizner, 2001; Hondzinski, Soebbing, French, & Winges, 2016). Manual length estimations were determined as displacements by subtracting fingertip start from fingertip end locations. Mean length estimation was calculated by averaging the displacements for each control trial, gaze condition, configuration orientation, and participant. To allow for direct comparisons across participants, a displacement error for each trial was calculated relative to the mean displacement in control trials for each gaze condition, configuration orientation, and participant. Normal distributions were assessed using the Shapiro-Wilk W test. Violations of sphericity were assessed using Mauchly's test statistic. Potential differences between free gaze control and experimental displacement means were determined using dependent *t* tests for each configuration orientation. Effects of gaze condition (free gaze, center fixation, finger fixation), configuration orientation (upright, rotated) on mean displacement were analyzed with a repeated measures ANOVAs and Tukey's post-hoc tests. Effect size (ES) corresponding to partial eta squared provided insight into the strength of relationships for significant outcomes. Strength of ES were considered small ≤ .25 and large ≥ .40 with medium between .25 and .40 (Cohen, 1969). Relationships between perception and action were determined across participants through visual inspection of mean data and by correlating movement displacement errors with

percentages of illusory responses for each configuration orientation and gaze condition pairing using Spearman correlations. We also assessed relationships between viewing time and displacement errors for each configuration in the free gaze condition using Spearman correlations to determine whether associations existed and might explain error differences. These latter correlations included across participant means and individual trials for within subject comparisons. Significance level was set at $\alpha = .05$ for all analyses performed using Statistica 13.3 (Dell, Hopkinton, USA).

RESULTS

Perception judgments

We required perceptual responses prior to movements to determine the illusory influences of configurations on visual perceptions. Results showed that participants in this study revealed perceptual judgments that were influenced by the V-H illusion regardless of gaze condition. Data in Table 4.1 represent the percentages of perceptual judgment responses for each gaze condition and configuration orientation pair. Participants often perceived equal horizontal and vertical segments when the bisecting segment was shorter than the bisected segment and revealed few correct responses in these instances (see bold values in Upright and Rotated columns, Table 4.1). Responding “equal” or “vertical” for upright and “equal” or “horizontal” for rotated configurations indicated that participants perceived a longer bisecting segment, when it was actually shorter than the bisected segment. These data indicated that participants in this study indeed revealed V-H illusory influences on visual perception. Moreover, although six of the twelve participants produced 100% incorrect, thus illusory responses, Figure 4.2 reveals that illusory judgments varied across people and configuration orientations.

Table 4.1. Perceptual judgment response percentages

Gaze Condition	Response	Upright	Rotated
Free Gaze	Vertical	22.9	**28.8**
	Equal	66.9	65.3
	Horizontal	**10.2**	5.9
Center Fixation	Vertical	26.3	**17.7**
	Equal	68.6	76.1
	Horizontal	**5.1**	6.2
Finger Fixation	Vertical	27.2	**20.3**
	Equal	68.4	74.6
	Horizontal	**4.4**	5.1

Note**:** Bold **numbers** are Percent of correct responses.

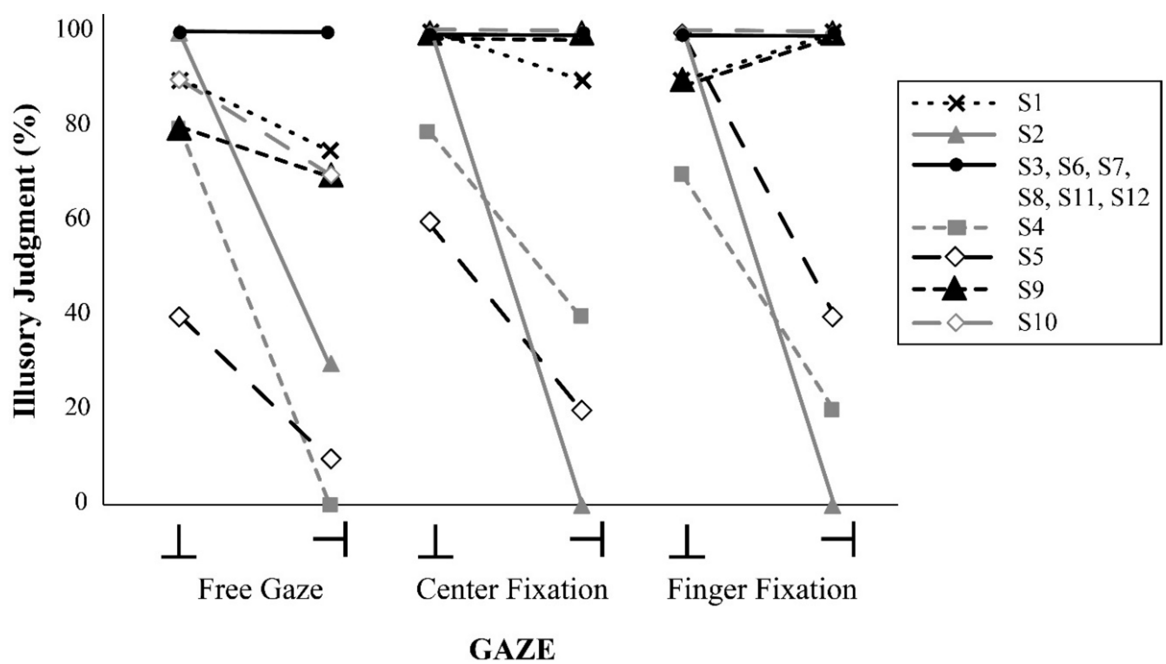

Figure 4.2. Percentages of illusory responses for each of the 12 participants are shown for each configuration (see symbols) in free gaze, center fixation, and finger fixation gaze conditions. (caption cont.'d.)

Different symbols represent individual participants (S1-S12). Lines represent connections between configuration percentages for each participant within a gaze condition. Percentages indicate the portion of illusory responses of the number of total responses.

Perceptuomotor control

In order to assess gaze direction before and during movement in the free gaze condition, we examined viewing time by area. Figure 4.3 depicts percentage of time spent viewing the configuration, start dot, movement space, and elsewhere before and during movements for each configuration. Note the similarities between viewing times for upright and rotated configurations. Participants spent most time before movement on the configuration and most time during movement on the movement space. The greatest percentage of viewing time before movement included the time it took participants to provide their perceptual judgment responses. To determine if viewing times associated with movement performance, we correlated viewing times on the four areas with displacement errors for each configuration. On average, significant correlations were determined when viewing the upright configuration before ($r = .65$) and during ($r = .70$) movement and when viewing the movement space for the rotated configuration during movement ($r = -.60$). These results indicated the following. The participants who viewed the upright configuration most before and during movement produced the greatest positive errors, thus manually overestimated bisecting segment length. The participants who viewed the upright configuration least produced the greatest negative errors, thus manually underestimated bisecting segment length. The participants who viewed the rotated configuration movement space most during movement produced the greatest negative errors, thus manually underestimated bisecting segment length. The participants who viewed the rotated configuration movement space least during movement produced the greatest positive errors, thus manually overestimated bisecting segment length. Within subject correlations revealed few significant associations of viewing time

within an area and displacement errors for each configuration. Only 11 of the 96 correlations were significant to suggest no consistent viewing time trends by area within participants.

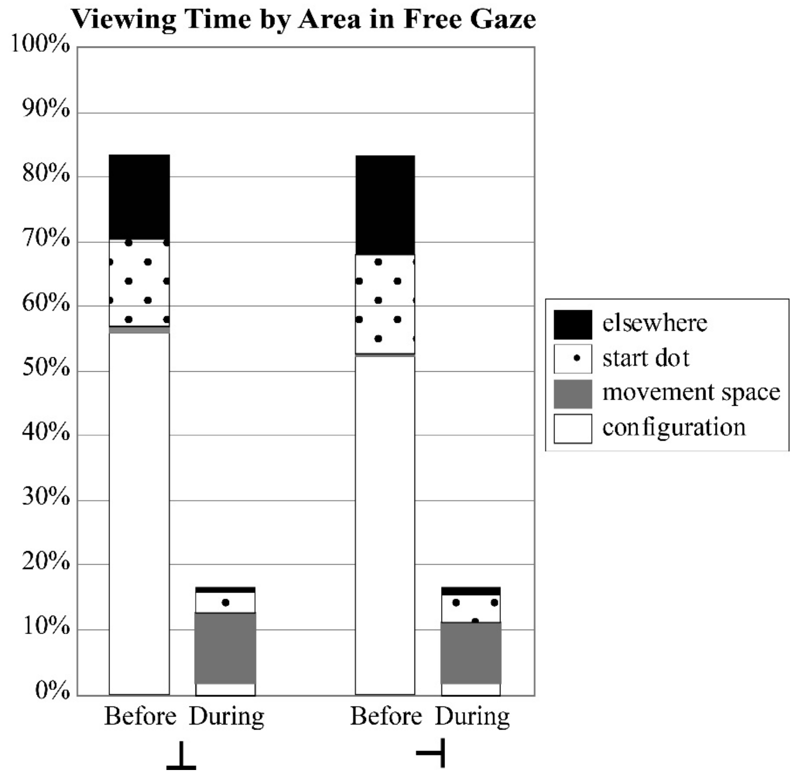

Figure 4.3. Percentage of time spent viewing at the configuration, start dot, movement space and elsewhere before movement and during movement in the free gaze condition.

Raw data of manual length estimations for start and end locations of two participants are shown for the rotated configuration (Figure 4.4). One participant often overestimated the bisecting segment lengths for rightward movements for each gaze condition more than the average across participants (Figure 4.4A). The other participant often underestimated the bisecting segment length in free gaze and finger fixation conditions (Figure 4.4B).

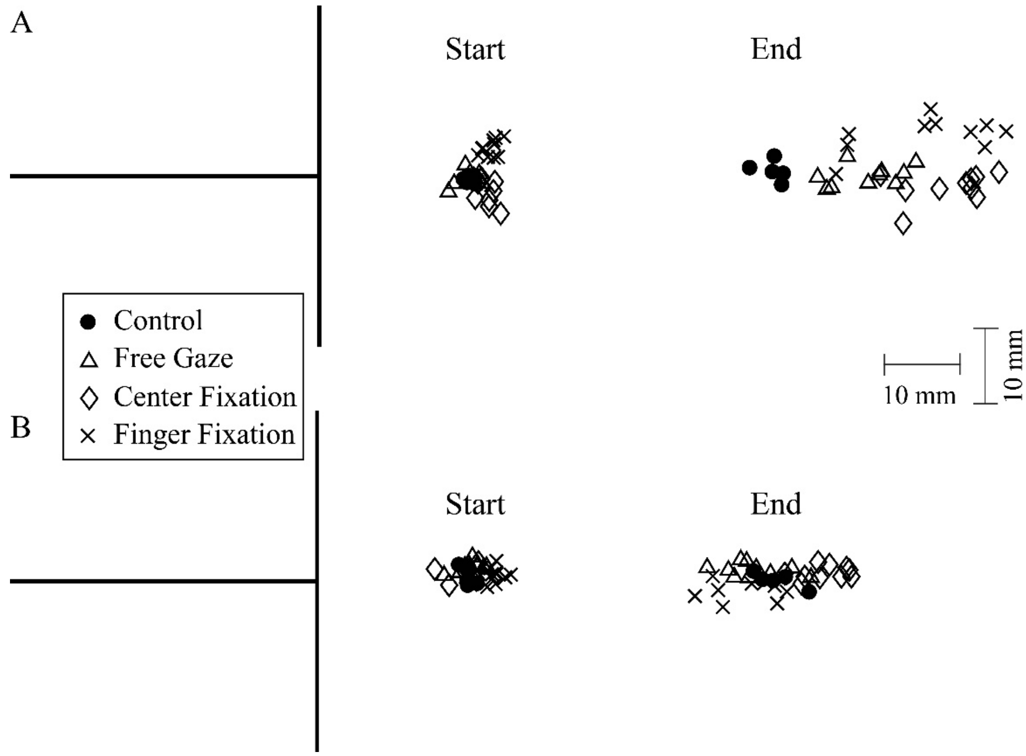

Figure 4.4. Start and end locations for manual length estimations for each trial of two participants for the rotated configuration. Filled circles represent start and end locations in control trials. Open triangles, open diamonds, and crosses depict the free gaze, center fixation and finger fixation conditions, respectively. A participant who overshot movement end of control trials for rightward movements in each gaze condition (A). A participant who undershot and overshot movement end of control trials for different gaze conditions (B). Distance between start and end locations represent the manually estimated bisecting segment length.

To determine whether manual estimations of the bisecting segment length of the V-H illusion would be longer for experimental and control trials during free gaze, we compared effects of control and experimental displacement means using a dependent *t* test for each configuration orientation. Results revealed no significant displacement differences for upright ($t(1,11) = -.56$, $p = .58$) or rotated ($t(1,11) = 1.39$, $p = .19$) configurations and indicated similar displacements between experimental and control means (Figure 4.5).

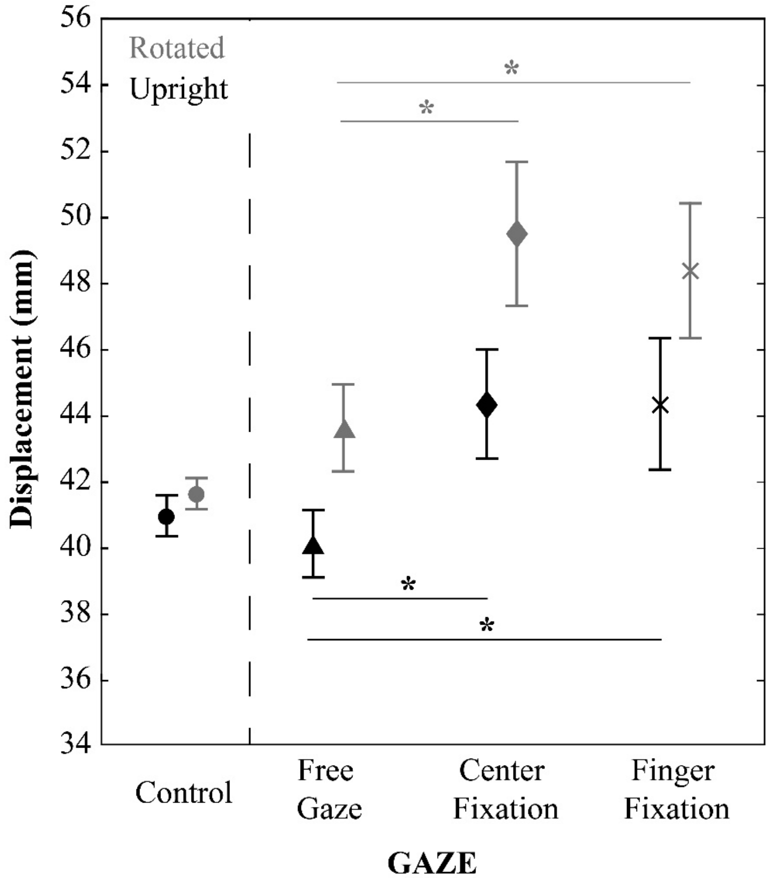

Figure 4.5. Mean displacement for manual length estimations (±1 SE) of rotated (gray) and upright (black) configuration orientations for control and gaze conditions are shown. Horizontal lines with asterisks represent the significant differences between corresponding means at the line ends for rotated (gray) and upright (black) configurations.

To test whether manual estimations of the bisecting segment length of the V-H illusion would be longer for upright than rotated configurations and longer for central fixation than free gaze, we analyzed effects of configuration orientation and gaze condition on mean displacement (Figure 4.6). Results, which revealed a significant main effect of configuration orientation on displacement ($F(1,11) = 26.71$, $p < .001$, ES = . 71), indicated that the mean displacement during rightward movements for the rotated configuration (mean ± SD = 47.2 mm ± 5.41 mm) exceeded the displacement during downward movements for the upright configuration (43.0 mm ± 4.59 mm). Results, which revealed a significant main effect of gaze condition on displacement

(F(2,22) = 6.34, p < .01, *ES* = .37), indicated that the displacement for center fixation (46.9 mm ± 6.44 mm) and finger fixation (46.4 mm ± 6.59 mm) exceeded those for free gaze (41.9 mm ± 3.71 mm). The overestimation of bisecting segment lengths indicated that on average participant's movements were influenced by the V-H illusion in center fixation and finger fixation conditions regardless of configuration orientation.

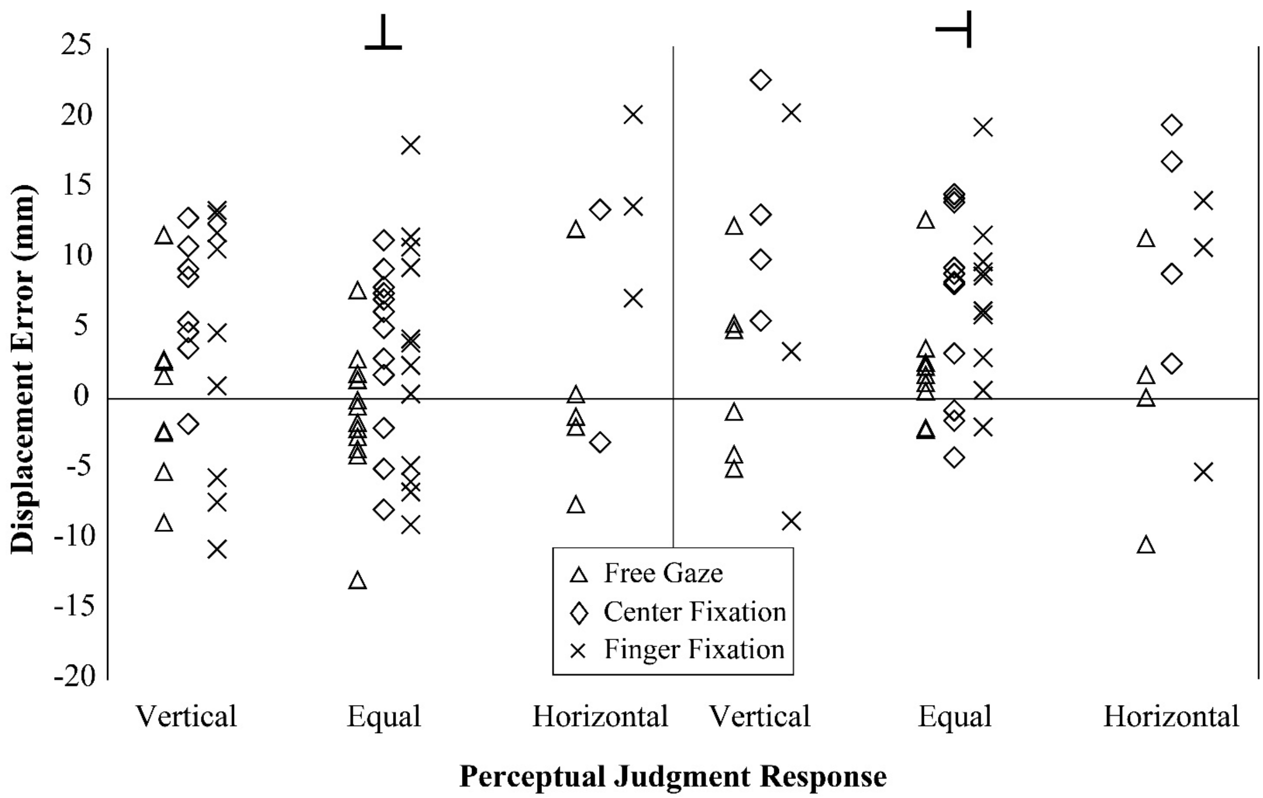

Figure 4.6. Mean displacement errors for each gaze condition (free gaze-triangle, center fixation-diamond, finger fixation-cross) are shown for upright (left) and rotated (right) configuration orientations according to perceptual responses. Each symbol represents the mean error for one participant for the associated gaze condition and corresponding to the given perceptual response provided at the bottom of the graph. Note, some participants did not provide vertical, equal, and horizontal responses within each gaze condition.

In order to determine whether perception and action varied across participants for the V-H illusion, we assessed the relationship between displacement errors and perceptual responses.

First, we plotted average displacement error for each participant against their corresponding perceptual response for each configuration. For example, imagine a participant stated “vertical” eight times and “equal” twice in the free gaze condition for the upright configuration. Two triangles would be plotted; one over the vertical response representing the mean displacement error of eight trials and one over the equal response representing the mean displacement error of two trials. With underestimations and overestimations for each perceptual response, these data revealed that manual length estimations did not correspond to perceptual responses in a systematic manner across participants. We then quantified the relationship between perceptual judgments and manual length estimations by determining whether the participants exhibiting greater illusory responses also exhibited greater displacement errors. Results revealed a significant negative correlation between illusory judgment percentages and displacement error for the upright configuration only in the finger fixation condition ($r = -.59$). Participants with the largest positive errors in this condition provided the fewest illusory judgments. Together, these outcomes indicated opposing results between perceptual judgments and manual length estimations in some participants.

DISCUSSION

The primary aim of this study was to investigate the influence of gaze direction on perception and action for the V-H illusion. We first determine whether participants recruited for this study succumbed to the V-H illusion for perceptual judgments and briefly discuss how these results compare with others in the literature. We then address the main hypothesis that perceptuomotor control for manual length estimations also succumbed to V-H illusory influences, which are dependent on gaze direction and configuration orientation. We include

discussion on the relationship between perceptual responses and movement performance and discuss how the evidence improves our understanding of the associated sensorimotor control.

Perceptual judgments

To determine the V-H illusory effects on visual perceptions in our participants, we analyzed data involving the upright (Figure 4.1D) and rotated (Figure 4.1E) IT configurations with the bisecting segment length less than the bisected segment length. The bisecting segment of each configuration frequently appeared longer than the bisected length to indicate V-H illusory influences in our participants. These mean data support the well-established idea that V-H illusory effects on perception followed bisection influences (Charras & Lupiáñez, 2010; Cormack & Cormack, 1974; Finger & Spelt, 1947; Künnapas, 1955; Mamassian & de Montalembert, 2010; Thompson & Schiffman, 1974; Wolfe et al., 2005; Gavilán et al., 2017; Renier et al., 2006). The individualized weighting of illusory influences, which varied across participants and showed the existence of idiosyncratic differences in perceptual judgments (Wolfe et al., 2005), also revealed bisection influences on perceptual judgments. Additionally, fewer illusory response means for the rotated configuration (77.7%) than the upright configuration (93.4%) support results of others that reveal stronger illusory perceptual influences for upright than rotated configurations (Charras & Lupiáñez, 2010; Cormack & Cormack, 1974; Finger & Spelt, 1947; Künnapas, 1955; Mamassian & de Montalembert, 2010; Thompson & Schiffman, 1974; Wolfe et al., 2005). Although only some data for individual participant's perceptions appeared to follow these between configuration trends (Figure 2), the use of categorical responses did not allow for more direct comparisons of illusory extent. Slightly fewer illusory response means for free gaze (80.5%) compared to center fixation (88.6%) and finger fixation (87.7%) support the evidence indicating greater illusory perceptual influences for

intersection (center) fixation than gazing freely (Chouinard et al., 2017). The greatest percentages in center fixation, involving greater gaze stability, contrast evidence that less gaze stability for perception increases perceptual judgments for an illusion (Murakami, Kitaoka, & Ashida, 2006), supporting the potential effect of gaze direction on perceptual illusory influences, instead of gaze instability.

Bisection and perceptuomotor control

The significant main effects of gaze condition and configuration orientation on displacement revealed the major outcomes of this study. Results clearly demonstrated V-H illusory effects on perceptuomotor control for central and finger fixations for each configuration of the given task. Manual length estimations of the bisecting segment for center fixation and finger fixation were greater than free gaze, the latter of which did not differ significantly from control trials. Similar results were found when people used a mouse to draw an estimated length of a single perpendicular segment to produce an IT (Gavilán et al., 2017). In this case, people drew shorter bisecting segments and longer bisected segments to suggest that they underestimated bisected segment lengths and overestimated bisecting segment lengths. Thus, using curved pointing movements in the present study, in which movement distance did not directly match estimated bisecting segment lengths, did not seem to matter as expected illusory influences remained for mean data in this perceptuomotor task.

Configuration orientation and perceptuomotor control

Perceptuomotor control for manual length estimations, as determined through curved pointing movements, depended on configuration orientation. Directing movements rightward for rotated configurations resulted in manual length estimations greater than directing movements downward for upright configurations (Figure 5). Remember that participants produced a greater

percentage of illusory perceptual responses for upright than rotated configurations (Table 1) to provide perceptual responses similar to elsewhere (Charras & Lupiáñez, 2010; Cormack & Cormack, 1974; Finger & Spelt, 1947; Künnapas, 1955; Mamassian & de Montalembert, 2010; Thompson & Schiffman, 1974; Wolfe et al., 2005). The greater overestimations of bisecting segment length observed for rotated compared to upright configurations in our study oppose, thus cannot be explained by, the corresponding perceptual judgments. The perceptuomotor differences by configuration orientation may result from perceptuomotor transformations of visual space, which differ for vertical and horizontal coordinates (Crawford 1994; Soechting and Flanders 1989a; Soechting and Flanders 1989b). Transformation inconsistencies would explain why the manual length estimations of the bisecting segment for rotated configurations often exceeded upright configurations, rather than the opposite as with perceptual responses.

Gaze direction and perceptuomotor control

Restricting gaze direction altered perceptuomotor control for participants in this study. Directing gaze toward the configuration intersection or the finger and its movement space, resulted in manual length estimations which exceeded free gaze (Figure 5). Results, showing that manual length estimations for center fixation exceeded free gaze, complement previous outcomes for perception using the same conditions (Chouinard et al., 2017). The greater retinal stabilization accompanying center fixation contrasts evidence revealing that greater illusory effects accompany more gaze shifts for manual length estimations involving grasp aperture for the Müller-Lyer illusion (van Doorn, van der Kamp, de Wit, & Savelsbergh, 2009). The Müller-Lyer illusion corresponds to either segment a or b with corresponding arrowheads, individually (Figure 1a). Participants in the van Doorn et al study also spent most of their time viewing the surrounding arrowheads of Müller-Lyer illusion. When combined with the finger fixation results

of the current study, we reasoned that data support the role of gaze direction in enhancing illusory influences over manual length estimations rather than gaze shifts. The viewing time data during free gaze also supports that illusory influences over manual length estimations depend on gaze direction. With no restrictions, people chose to gaze most often at the configuration before movement and the movement space during movement and produced manual length estimations which did not differ significantly from control trials. Unlike perceptual responses, allowing people to look freely greatly reduced and/or eliminated the illusory effect over perceptuomotor control. Thus, V-H illusory influences over manual length estimations were strongest when gaze was restricted toward the configuration intersection or the hand and its movement space.

Perception and perceptuomotor control

We designed a study that offers greater insight into the potential links between perception and action. It appears that on average perceptuomotor control matched illusory responses. The observed movement displacement in center fixation and finger fixation conditions, which exceeded free gaze, could result if participants' estimations matched a perceived longer bisecting segment. The present results support the existence of V-H illusory perceptions corresponding to relatively longer bisecting segments than bisected segments (de Montalembert & Mamassian, 2010; Wolfe et al., 2005). These data support the application of an illusory construct to explain mean manual length estimations of the bisecting segment of the V-H illusion, which support mean perceptual judgments. Because illusory influences on perceptual responses and manual length estimations relied on gaze direction and could differ across participants, it appears that illusory influences over perceptual judgements and manual length estimations may be task dependent.

Similar V-H illusory effects on perceptual judgments and manual length estimations did not exist when considering configuration orientation effects and associations between perceptual responses and perceptuomotor outcomes across participants. As mentioned previously, manual length estimations for the bisecting segment lengths of upright configurations exceeded those for rotated configurations to oppose corresponding perceptual judgments. In addition, we found no significant or significantly negative correlations between displacement errors and percentages of illusory responses across participants to demonstrate clear dissociations between perceptual responses and manual length estimations in our study. This dissociation provides support for the two-visual-systems hypothesis (Goodale & Milner, 1992).

We also consider that the use of a planning-control model to explain reduced or eliminated illusory effects over movement control may be superior to the two-visual-systems model for perception and action. The basic premise of the planning-control model is that visual illusions can influence movement control only during initial stages of a movement and the illusory effect decays with time and can disappear near movement completion as a result of online motor control (Glover & Dixon, 2001). Based on this model and perceptual similarities across gaze conditions and configuration orientations, motor planning for our participants should also be similar across gaze conditions and configuration orientations, leaving online control to vary. The more time our participants spent viewing the movement space for the rotated configuration in free gaze, the smaller the errors, supporting a greater decay of illusory influences. The more time people spent viewing the upright configuration in free gaze, the larger the errors, supporting less decay of illusory influences. Restricting gaze in the center fixation condition likely limited illusory decay too. Thus, results of free gaze and center fixation provide support for the planning-control model. In contrast, restricting gaze in the finger fixation

condition would allow for greater decay of illusory influences, yet illusory influences remained, thus cannot be explained by the planning-control model. Therefore, we determined that the dissociations between perceptual responses and manual length estimations in our data provided evidence to support the two-visual-systems hypothesis (Aglioti et al., 1995; Bradshaw & Watt, 2002; Bruno & Bernardis, 2002; Ganel et al., 2008; Goodale, 2014; Haffenden & Goodale, 1998; Milner & Goodale, 1995).

CONCLUSION

Bisection influences on manual length estimations which depended on gaze direction and configuration orientation differed from bisection influences on perceptual judgments to reveal support for a dissociation between perception and action. We concluded that exploitation of simple deceptive visual cues can provide general guidance of upper limb sensorimotor control according to the V-H illusory influences given the correct performance parameters.

CHAPTER 5. VERTICAL-HORIZONTAL ILLUSORY EFFECTS WITH GAZE RESTRICTIONS DO NOT CHANGE LENGTH ESTIMATIONS USING STEPPING MOVEMENTS: STUDY 3

INTRODUCTION

The two–visual-systems hypothesis represents a dissociation between control for perception and action (Goodale & Milner, 1992). Support for the hypothesis stems from data which reveal that visual illusions influence perceptual judgments and movements, differently. For example, altering a person's perception according to a visual illusion does not guarantee alterations in the corresponding movement according to the same illusion (Bartelt & Darling, 2002; Haffenden & Goodale, 1998; Westwood, Chapman, & Roy, 2000). In contrast, others report that visual illusions influenced a human's perception and movements, similarly (Elliott, Vale, Whitaker, & Buckley, 2009; Foster, Buckley, Whitaker, & Elliott, 2016; Foster, Whitaker, Scally, Buckley, & Elliott, 2015); thus contradicting the "two-visual-systems" hypothesis (Franz, Gegenfurtner, Bülthoff, & Fahle, 2000; Mendoza, Hansen, Glazebrook, Keetch, & Elliott, 2005). Variations across illusions, experimental procedures, and data analyses explain inconsistent results of influences of visual illusions on perception and action (Bruno, Bernardis, & Gentilucci, 2008; Kopiske, Bruno, Hesse, Schenk, & Franz, 2017).

The ability to utilize illusory influences to alter movement control is of interest because it has potential to positively influence movement in people with motor declines, due to healthy aging, disease, and/or injury. For example, the use of multiple vertical and horizontal segments on the rise and tread components of stairs, respectively, revealed greater vertical toe clearance for ascending one (Elliott et al., 2009) or several stairs (Elliott et al., 2009; Foster et al., 2015) than plain stairs for elders. Vertical segments on

the front surface of a low-height obstacle also associated with greater toe clearance when stepping over the obstacle compared to stepping over the obstacle without the vertical segments (Foster et al., 2016). Researchers emphasized that the low vertical toe clearance was one of risk factors of falling in elders (Tinetti, Speechley, & Ginter, 1988; Downton & Andrews, 1991). Thus, to reduce the incidence of falling, increasing vertical toe clearance has been suggested as a common strategy when stepping onto a raised surface for people who have vision problems (Elliott, Patla, Furniss, & Adkin, 2000; Patla & Vickers, 1997) or performing such movement with reduced illumination (Hamel, Okita, Higginson, & Cavanagh, 2005). These outcomes provide promise for illusory influences on perceptuomotor control in illuminated environments with eyes open and no limitation on gaze direction. However, allowing people to gaze freely can limit illusory influences on manual length estimations (see study 2 in chapter 4 and Yan & Honzinski, 2020). Thus, we reasoned that use of certain gaze strategies, gazing at the configuration and the movement, would also enhance illusory influences on step length estimations. Moreover, we use the present study to explore whether such illusion enhancement to lower limb occurs.

The well-known eye-hand coupling that occurs for upper limb movements is less common for the eye and foot. People often look ahead when asked to step on objects during walking, rarely watching their exact foot placement (Turano, Geruschat, Baker, Stahl, & Shapiro, 2001). Common use of an eye-foot decoupling strategy may affect the step displacement performances according to gaze direction in a different manner than that of the eye and hand. Interestingly, greater goal-directed inaccuracies accompany hand movements during visuomotor plane decoupling. People performing horizontal plane hand movements while viewing targets on a vertical plane produce greater errors than performing vertical plane hand movements (Dalecki,

Gorbet, & Sergio, 2019). Regardless of the potential eye-foot decoupling strategy, some studies confirmed illusory influences on spatial aspects of lower limb movements. Remember that the increased vertical toe clearance for ascending staircases and stepping across a low-height obstacle resulted from the presentation of 2D shapes on the vertical surface to alter vertical step performances. It is unclear whether presentations of vertical stimuli can influence horizontal stepping movements in the same manner. We kept this potential eye-foot decoupling strategy in mind when designing the current study, including conditions involving gaze anchoring on and off the movement of the stepping foot.

Some researchers explain that perception-action similarities and differences depend on the phase of movement using a planning-control model (S. R. Glover & Dixon, 2001). Visual illusions, which affect online control during the motor planning phase and can influence early motor execution, decay quickly to result in perception-action differences by movement end. Thus, influences on perception would influence the planning and early execution components of a stepping task but may not influence the actual step length. People often shift body weight, thus, displacements of the center of pressure (COP), prior to movement during motor planning phase of a step (Burleigh-Jacobs, Horak, Nutt, & Obeso, 1997; MannHagy, White, & Liddell, 1979; Ruget et al., 2008). The displacement of COP towards the swing leg along the medial-lateral direction is known as an anticipatory postural adjustment (APA) and refers to the concept that people adjust their body weight prior to a step initiation (Caderby et al., 2014; Mouchnino, Robert, Ruget, Blouin, & Simoneau, 2012; Sun, Guerra, & Shea, 2015). Thus, data recordings involved movements needed to process kinematics of step execution and forces needed to

calculate APA variables associated with step initiation to account for potential illusory changes in the motor planning process.

In this study, we used a forward step length estimation task to determine if participants' step displacements would follow vertical-horizontal (V-H) illusory influences similarly to the upper limb manual length estimations used previously (Yan & Honzinski, 2020). The standard V-H illusion is characterized by and inverted "T" (IT), in which people overestimate the vertical segment and/or underestimate the horizontal segment when the two perpendicular segments are physically equal in length (Figure 5.1A). Therefore, a movement displacement longer than the actual length of the vertical segment in the presence of the horizontal segment of the IT is expected for illusory influences on movement. Using remembered targets while performing a single step allowed us to test if short-term remembered illusion also affects lower limb motor control. We hypothesized that individuals' size estimates using a step would be more biased by the V-H illusion when they fixated their eyes on the center area of the configuration or remembered configuration during the step than when allowed to look down at their feet during the step after viewing the V-H illusion or after viewing the bottom end of a single vertical segment.

The purposes of this study were to determine: 1) whether size estimates of the vertical/bisecting segment length for the V-H illusion using step displacements exceeded corresponding size estimations of a vertical segment without the illusion using step displacements; 2) whether restricting gaze would influence size estimations of the vertical/bisecting segment length for the V-H illusion using step displacements; and 3) whether restricting gaze would influence performance during motor planning and early phase execution of the step.

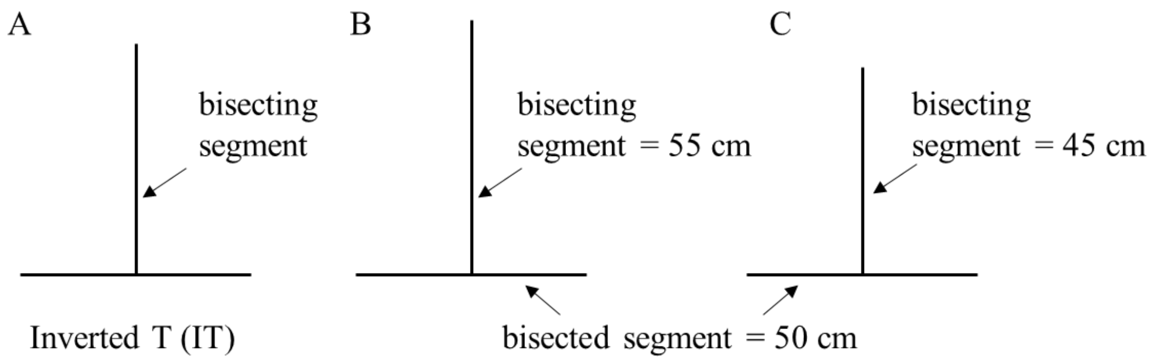

Figure 5.1. Inverted T (IT) with vertical and horizontal segments equal in length (A). Pictoral descriptions of long (B) and short (C) configurations of IT visual stimuli used in this experiment.

METHODS

Participants

Twenty college students (6 males and 14 females) who were unfamiliar with visual illusions participated in this experiment. They read and signed consent form prior to participation. Participants had no difficulty viewing targets on the projector screen at a distance of 4 meters away from each participant (visual acuity 20/30 or better on the Snellen eye chart assessment). The study was approved by the Institutional Review Board of Louisiana State University. Only data from 15 participants (12 females) were used for data analysis (mean age = 21 ± 1.2 years, mean body mass = 75 kg ± 22 kg). Reasons for removal of participants included that three did not follow the experiment instructions involving gaze direction and force plate recordings were missing for two.

Visual stimuli

The visual stimuli involved the IT configuration with 2 sizes such that the bisecting segment was 10% longer (55 cm) or shorter (45 cm) than the bisected segment (50 cm) (Figure 5.1B and 5.1C). Stimuli involved solid black line segments with a projected line width = 1 cm on a white background. In a control trial, a vertical segment of 55 cm or 45 cm was presented to

participants. Use of 2 lengths prevented memorization of one movement distance. The visual stimuli were designed and presented to participants using PsychoPy program (Peirce, 2007).

Experimental setup

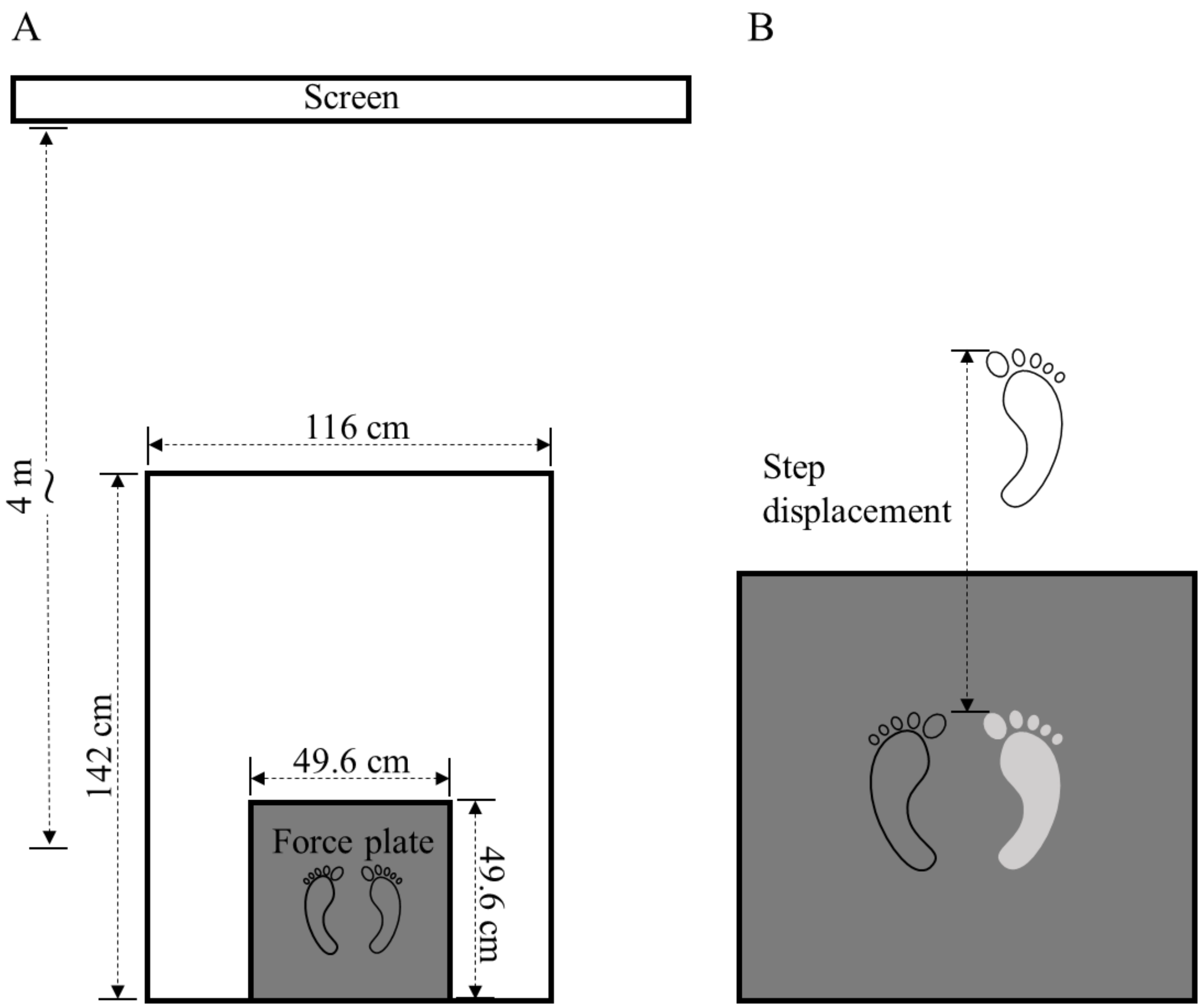

Figure 5.2. Experimental setup. Foot outlines on the force plate (gray square) represent start position. The force plate was surrounded on three sides by a platform of the same height (A). A cartoon depicting step displacement (B).

Figure 5.2A shows the experimental setup. Participants stood in the start position on a force plate (49.6 cm x 49.6.1 cm x 4.65 cm), surrounded on three sides by a platform of the same height. Chalk outlines of foot position provided the same start position throughout trials. A

screen, 311 cm x 196 cm, used for projecting visual stimuli, was positioned in a frontoparallel plane a distance of 4 m. The intersection of the IT configurations or the low end of a vertical segment (no horizontal segment in Figure 5.1 B and C) for control trials was projected at the participant's eye level (average eye level height = 158 cm ± 9 cm).

Experimental procedure

Barefooted participants stood upright on a force plate with their feet placed a self-selected preferred distance apart. Remember, chalk outlines of each foot position ensured consistent starting stance across trials (Figure 5.2). Prior to the experimental trials, investigators instructed participants to stand on the force plate and perform 5 practice trials of a forward comfortable step with their right preferred to get accustomed to procedural cues.

Participants performed perceptual judgment task prior to the perceptuomotor task for each experimental trial. After stimulus presentation of an IT configuration on the screen, participants viewed the IT intersection and orally responded "equal" when the segments appeared identical in length, "horizontal" when the horizontal segment appeared longer than the vertical segment, and "vertical" when the vertical segment appeared longer than the horizontal segment. Perceptual responses were recorded by hand and via audio in the gaze tracking video (see below). Stimulus presentation lasted for 4 s followed by an audio cue (programmed in advance using PsychoPy), which signaled participants to initiate a comfortably paced, single forward step with their right foot. Participants were asked to estimate the bisecting segment length so that their forward step displacement, described as their start right big toe/hallux position to the end position of the right big toe/hallux, was equal to the length of bisecting segment of the presented

configuration. Note that the foot of the supporting left leg remained in contact with the force plate throughout the step (Figure 5.2B). After they stepped, the investigator signaled them to move back to start position and prepare for the next trial using a “relax” command. Participants estimated the length of a single vertical segment with step displacements for control trials.

Participants performed the stepping perceptuomotor task under 3 gaze conditions. In the first condition, participants maintained gaze on the segment intersection of the IT throughout a trial (Target fixation—TF). In the second condition, after they viewed the intersection for 4 s and heard the auditory cue, participants looked down and performed the step. In this condition, they were allowed to look the feet or the step area only (Movement fixation—MF). In the third condition, again, after a 4 s viewing time on the IT intersection, the visual stimulus disappeared at the time of the audio cue and participants maintained gaze on the remembered location of the intersection while performing the step (Remembered target fixation—RTF). In control trials, participants looked at the lower end of the single vertical segment for 4 s after stimulus presentation prior to the audio cue which signaled them to look down and initiate a step.

Participants always performed the control trials last. The order of 3 gaze conditions (TF, MF, RTF) was randomized prior to data collection for each participant. Table 5.1 shows the distribution of 70 experimental trials. Participants were given rests between gaze conditions, allowed to rest between each two minute data collection period, and finished the experiment within 80 minutes.

Table 5.1. A summary of the number of trials.

Configurations	Target Fixation (TF)	Movement Fixation (MF)	Remembered Target Fixation (RTF)	Control
Long	10	10	10	5
Short	10	10	10	5

Data collection and processing

A 60 Hz binocular mobile eye tracker (SMI, Teltow, Germany) was used to check if participants followed task instructions for each gaze condition. We deleted and repeated trials when participants had obvious deviations in gaze by checking the point of gaze on the viewing field video during data collection. We ensured intersection fixation/bottom of vertical segment fixation of gaze prior to the step and on the movement space during a step for MF/control trials. We ensured intersection/remembered intersection location fixation of gaze prior to and during the step for TF and RTF trials. Trial deletions for incorrect gaze deviations accompanied corresponding trials during inspection of offline recorded viewing field video using B-Gaze software (SMI, Teltow, Germany).

Perceptual judgments

Perceptual responses were recorded by hand and recorded on the video of the mobile eye tracker and checked using B-Gaze software. We counted the number of experimental trials that the participants reported as vertical, equal, or horizontal. Dividing these numbers by total trial number within a gaze condition and size gave us the percentage for correct, incorrect, and illusory responses. Analyses of perceptual judgments for the long bisecting segment configuration did not allow for proper analyses because the correct and illusory perceptual responses overlapped. Thus, analyses of illusory responses were limited to the short size configurations.

Stepping task

A 2 cm diameter reflective marker was placed on the hallux and the heel of the right foot. Marker movements were recorded at 250 Hz using a 4-camera Qualisys system

(Qualisys Medical AB, SE). The three dimensional coordinate data of each marker were lowpass filtered using a Butterworth second order filter with 13 Hz cutoff frequency (Sinclair, Bottoms, Taylor, & Mahmood, 2017; Sinclair & Stainton, 2019). Toe velocity represented the differentiation of the hallux marker with respect time. Start and end of movement were determined when toe velocity was maintained below 5% of peak velocity for ≥ 100 ms before and after movement, respectively, similar to other reports (Yan & Honzinski, 2020; Adamovich, et al., 2001; Hondzinski et al., 2016). Step displacement represented the distance between start and end locations of the hallux marker in the horizontal plane. The maximum velocity of the hallux marker between movement start and end was used to determine peak velocity (PV) of stepping to offer insight into temporal aspects of the stepping movement.

A mobile AMTI force plate was synchronized with the Qualisys system to record forces due to body movement at 250 Hz (AMTI Watertown, MA, USA). Ground reaction force (GRF) in the vertical (z) direction and center of pressure (COP) in the x (medio-lateral) direction, provided from specialized software (AMTI Balance Clinic, Watertown, MA, USA) and synchronized with the Qualisys system, were filtered using a Butterworth fourth order filter with 13 Hz cutoff frequency (Koltermann, Gerber, Beck, & Beck, 2018). Two COP variables, represented APAs (Burleigh-Jacobs, Horak, Nutt, & Obeso, 1997) (Ruget, Blouin, Teasdale, & Mouchnino, 2008). We identified the time and amplitude of APAs associated with each step using the following procedures (Figure 5.3). The onset of APA in x-direction (COPx) was determined as the time that the COPx exceeded 1 mm (Azuma, Ito, & Yamashita, 2007). APA duration (time to peak COPx—COPtime) was determined as the difference between the peak COPx toward the swing leg and onset of COPx. APA amplitude (COPamp) was determined as the difference between COPx at peak and onset. A longer COPtime represents a measure of

imbalance (Remelius, Hamill, Kent-Braun, & Van Emmerik, 2008; Ruhe, Fejer, & Walker, 2011), while a greater COPamp accompanies longer and narrower steps during compensatory stepping movements (Ruhe et al., 2011). The peak vertical ground reaction force in the z-direction (peakGRFz) was determined between the peak COPx and ≤ 20 ms after the PV. The peak ground reaction force amplitude was determined as the distance between peakGRFz and GRFz just prior to onset of COPx normalized by each participants' GRFz just prior to onset of COPx (GRFampN). GRFampN represents the propulsive force of the step.

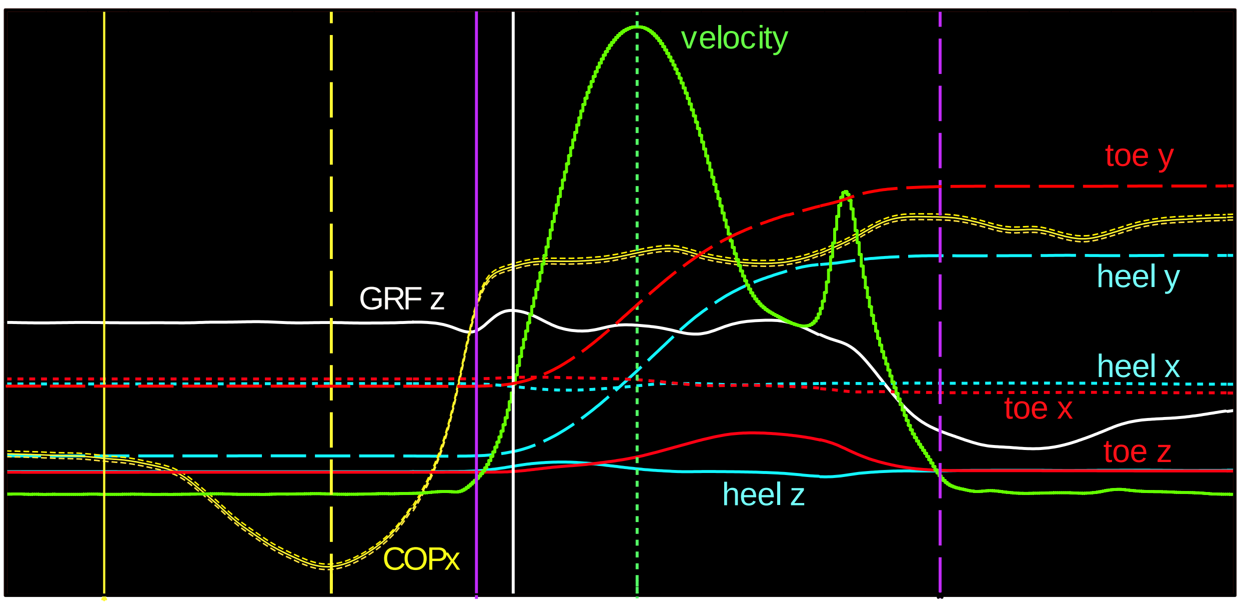

Figure 5.3. Data marking for one participant, #3. Yellow vertical lines represent the onset of COPx (solid) and peak COPx (dashed). Purple vertical lines represent the start (solid) and end (dashed) of stepping movement. The dotted green vertical line represents the time of peak step velocity. The vertical white line represents the time of peakGRFz.

Statistical analyses

Mean step displacement was determined for each gaze condition, configuration size, and participant. Other variables of interest included illusory percentages, mean COPamp, mean COPtime, and mean GRFampN for each gaze condition, configuration

size, and participant. The Shapiro-Wilk W test was used to assess existence of normal distributions. Mauchly's test statistic assessed violations of sphericity. Effects of configuration size (long, short) and gaze condition (TF, MF, RTF) on mean variables and their variability (standard deviation) were analyzed with repeated measures ANOVAs (Tukey's post-hoc tests). Application of Friedman ANOVAs to each non-normally distributed variable and Wilcoxon matched pairs tests with Bonferroni corrections provided insights into size and gaze effects on those variables. Effect size (ES) corresponding to partial eta squared provided insight into the strength of relationships for significant outcomes. ES strength was considered small $\leq .25$, large $\geq .40$, or medium between .25 and .40 (Cohen, 1969). We determined whether significant associations existed between step displacement and COPamp, COPtime, GRFampN, and PV across and within participants using Spearman's correlations. Alpha level was 0.05 for all analyses, unless corrected.

RESULTS

Perceptual judgments

We recorded perceptual responses prior to a step to assess the V-H illusory influences on perceptual judgments for the short configuration. Table 5.2 shows the associated perceptual judgment response percentages in the three gaze conditions. Fourteen out of fifteen participants perceived longer bisecting segment and/or equal bisecting and bisected segments when presented with a short bisecting segment. Only one person reported "horizontal" on some trials. Clearly, illusory responses for most participants in this study were 100% for each gaze condition to confirm strong V-H illusory effects on perceptual judgements.

Table 5.2. Perceptual Judgment Response Percentages for the Short Configuration**.**

Target Fixation (TF)			Movement Fixation (MF)			Remembered Target Fixation (RTF)		
Vertical	Equal	Horizontal	Vertical	Equal	Horizontal	Vertical	Equal	Horizontal
56%	40%	**4%**	57%	41%	**2%**	57%	39%	**4%**

Bold numbers: Percent of correct responses.

Stepping task

Mean step displacement for each participant is shown for each gaze condition and the control condition (Figure 5.4). These data show that mean step displacement varied across participants within each gaze condition and the control condition. Review of individual participant's data revealed varying trends across these conditions.

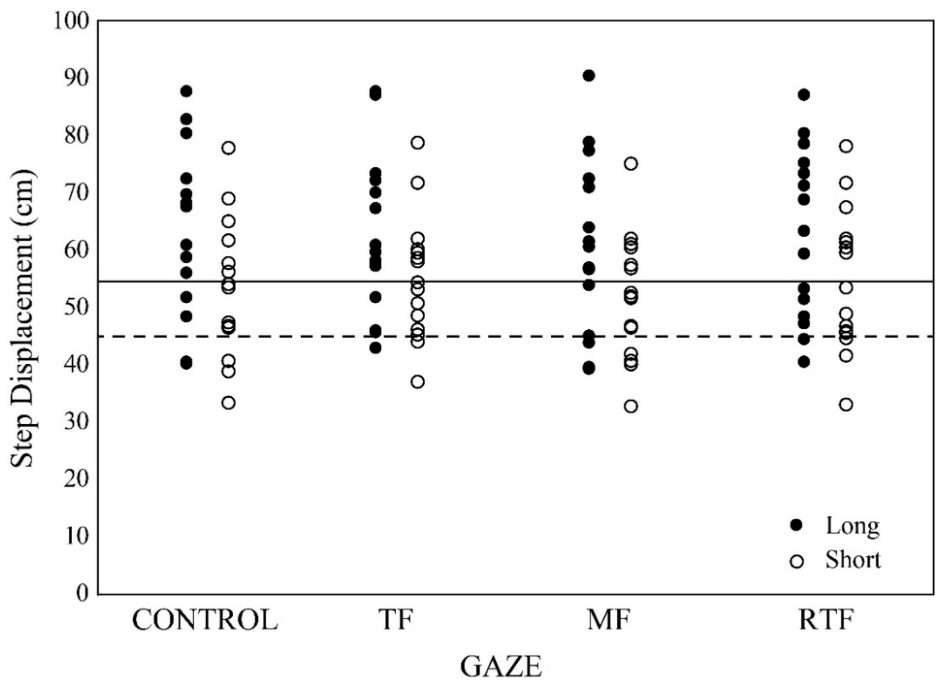

Figure 5.4. Mean step displacement is shown in for each participant for each gaze condition and the control condition. The solid and open circles represent step displacements produced for long and short configurations, respectively. The horizontal lines stand for the actual length on the projector screen, solid for long (55 cm), and dashed for short (45 cm).

To explore whether length estimations of the V-H illusion using stepping movements would differ for different sizes among gaze directions, we analyzed effects of configuration size and gaze condition on variables of interest. Figure 5.5 shows the results for mean step displacement, mean PV, and mean GRFampN. A significant main effect of configuration size on step displacement indicated that participants displaced their foot more when presented with long than short configurations ($F(1,14) = 61.90$, $p < .001$, ES = .82, Figure 5.5A) revealing that participants adjusted step displacement according to size. Significant main effects of configuration size ($F(1,14) = 59.17$, $p < .001$, ES = .81, Figure 5.5B) and gaze condition ($F(2,28) = 33.26$, $p < .001$, ES = .70, Figure 5.5C) on PV were also observed. Participants used less PV for short than long configurations and less PV in MF condition than RTF and TF conditions. Similarly, results revealed significant main effects of configuration size ($F(1,14) = 10.60$, $p < .01$, ES = .43, Figure 5.5D) and gaze condition ($F(2, 28) = 17.49$, $p < .001$, ES = .56, Figure 5.5E) on GRFampN to indicate that participants exerted greatest vertical forces for the long configuration and in TF and RTF conditions. Moreover, results of *t* tests indicated no significant differences between MF and control conditions for step displacement ($t(14) = 1.37$, $p = .19$), PV ($t(14) = -.18$, $p = .86$), or GRFampN ($t(14) = -1.77$, $p = .10$) to reveal no effect of the V-H illusion on step displacement, PV, and GRFampN when people look down during stepping.

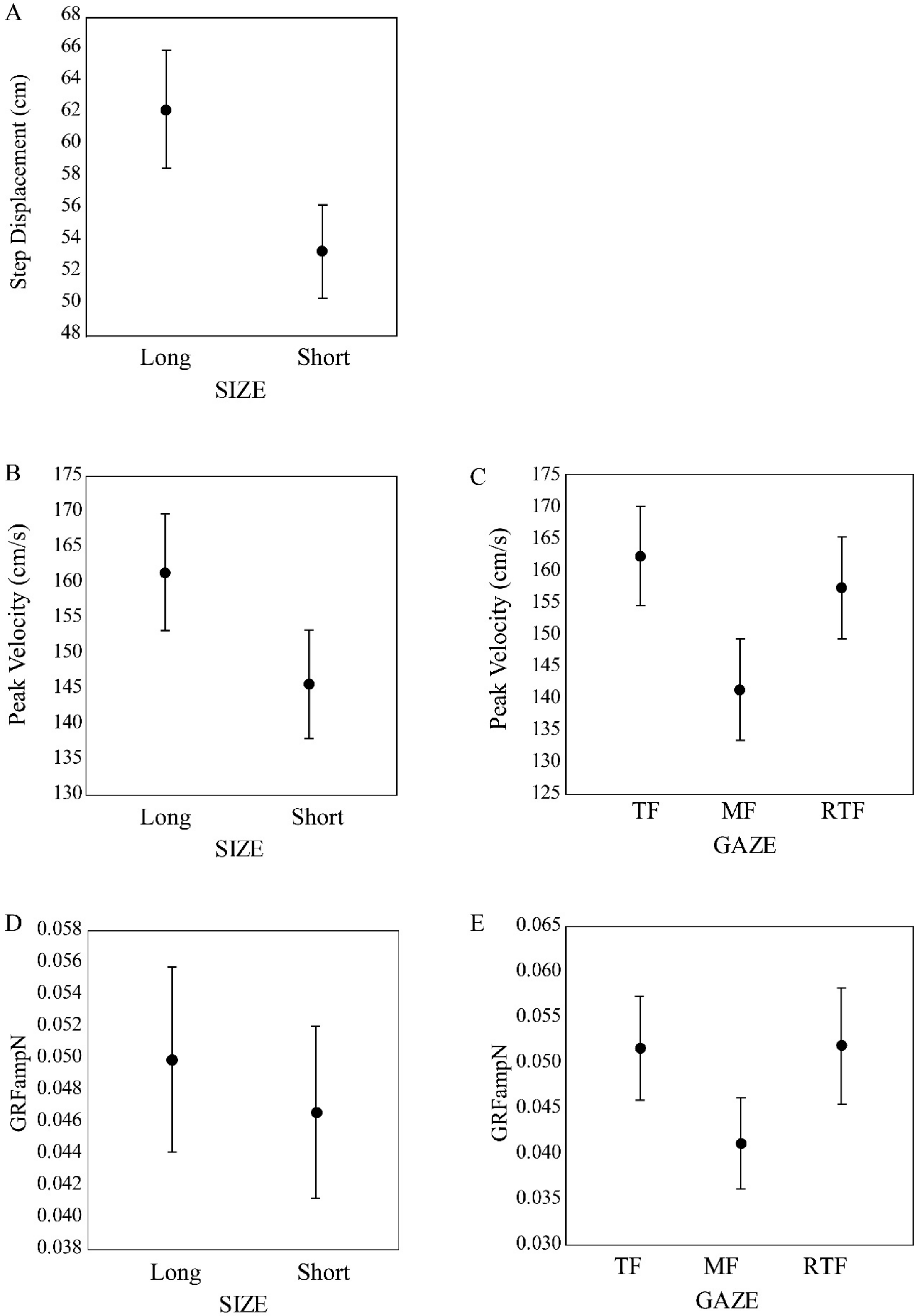

Figure 5.5. Main effects of size configuration and/or gaze condition on step displacement (A), PV (B and C), and GRFampN (D and E).

To determine whether size of the configuration or gaze restrictions influenced participant's abilities to plan a movement, we examined the main effects of configuration size and gaze condition on APA related variables: COPtime and COPamp. Results showed a significant main effect of gaze condition on COPtime ($F(1.43,20.08) = 4.20$, $p < .05$, ES = .23) and COPamp ($F(2,28) = 25.09$, $p < .001$, ES = .64), indicating that participants spent longer time to reach the peak COPx and produced a greater COPx amplitude (left panel, Figure 5.6) in TF and RTF conditions than MF condition. The significant interaction of configuration size x gaze condition for COPtime ($F(2,28) = 3.84$, $p < .05$, ES = .22) revealed that the greater COPtime observed for MF condition only existed for the short configuration (right panel, Figure 5.6).

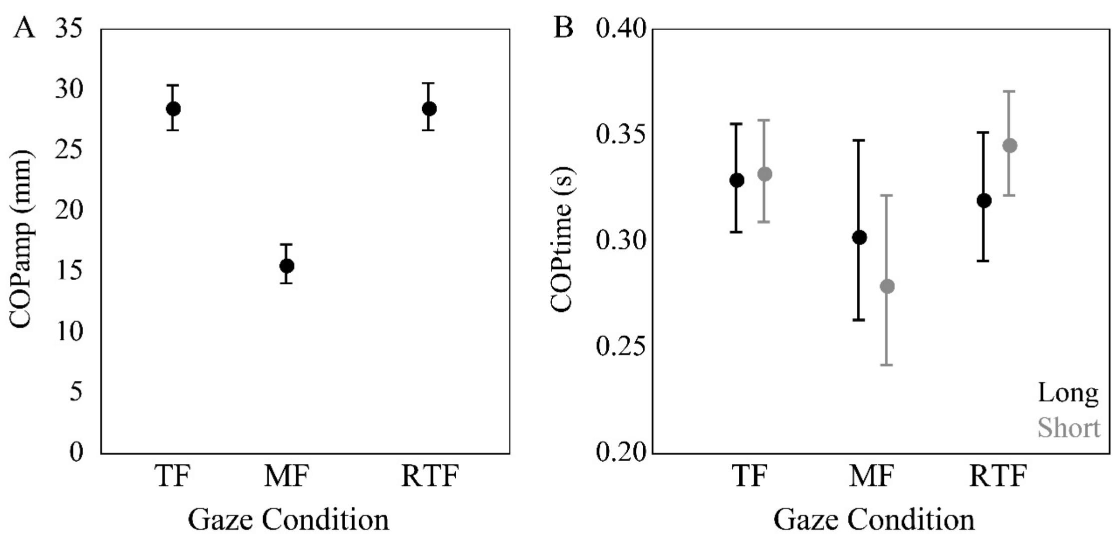

Figure 5.6. Main effect of gaze condition on and COPamp (A) and the interaction of configuration size x gaze condition on COPtime (B).

To assess whether step displacement associated with temporal aspects and motor planning, we correlated PV, GRFampN, COPtime, and COPamp with step displacement for each configuration (Figure 5.7). Significant positive correlations were observed between step displacement and PV in the three gaze conditions for each configuration size across participants. These results indicated that participants who achieved greater PV displaced the foot more

regardless of gaze direction and configuration size. Within subject correlations of PV and step displacement only revealed significant correlations for 6 participants or less for each configuration size and gaze condition pairing (1 for long TF, 5 for long MF, 3 for long RTF, 5 for short TF, 6 for short MF, 5 for short RTF) to indicate few within subject associations between step displacement and PV. With few significant within subject correlations between step displacement and GRFampN (4/90), COPtime (6/90), and COPamp (4/90) and no significant across participant correlations ($p < .05$) we determined that these variables did not correlate uniformly with step displacement across or within participants. These results suggest no associations of APAs and vertical ground reaction forces with step displacement in our participants.

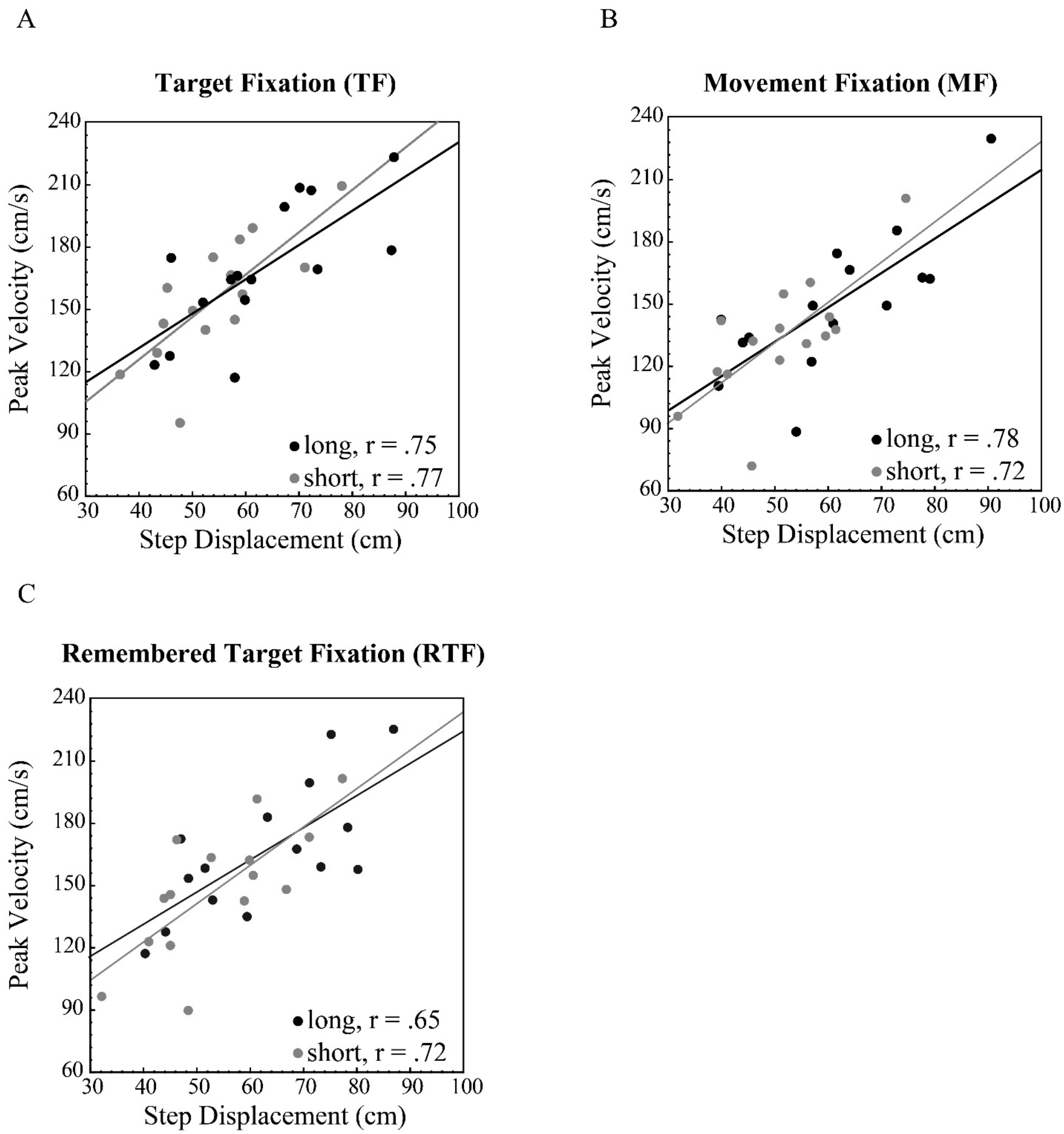

Figure 5.7. Significant positive correlations existed between step displacement and PV for long (black) and short (gray) configurations in each gaze condition. Each data point represents the mean PV plotted against mean step displacement for one participant in the given condition. Black and gray lines represent a linear fit to the corresponding data for long and short configurations.

DISCUSSION

The primary aim of this study was to determine whether size estimates using stepping movements with restricted gaze directions would be influenced by the V-H illusion. We first discuss the effects of V-H illusory influences on perceptual judgments in the context of the existing literature. Then, we discuss the effects of configuration size and gaze condition on step displacement and other variables associated with stepping and include discussion on the relationship between the illusory influences on performance measures. Discussion includes application of our findings to the relationship between perception and action and how our results contribute to visuomotor control for the lower extremity.

Perceptual judgments

In the present study, participants perceived a longer bisecting segment length than then the length of the horizontal segment of the V-H illusion even when presented with the short configuration, in which the bisecting segment was actually shorter than the bisected segment. Thus, participants in the present study revealed bisection influences on perception similar to others (Finger & Spelt, 1947; Gavilán, Rivera, Guasch, Demestre, & García-Albea, 2017; Wolfe, Maloney, & Tam, 2005). Restricting gaze fixation on the intersection of the vertical and horizontal segments of the IT V-H illusion produced high percentages of illusory responses on perceptual judgments (Table 5.2). Together these findings support previous reports that gaze restrictions produce the strong effects on perceptual judgments (Chouinard, Peel, & Landry, 2017; Yan & Honzinski, 2020).

Length estimations

Results revealed that step displacement changed according to size of the V-H illusion. The configuration size effect on step displacement, which revealed longer step displacements for the long compared to short configurations, indicates that participants can alter segment length estimations relative to the length of the bisecting segment of the V-H illusion. Regardless of the accurate relative size estimations, length estimations varied greatly across participants for control trials and gaze conditions (see Figure 5.4) to reveal common inaccurate length estimations of vertically oriented segments using the lower limb displacements. Although these results do not address the purposes of this study, they at least demonstrate that participants tried to follow task instructions. Furthermore, although some people overestimated bisecting segment lengths according to the V-H illusory expectations, others did not, and emphasize the existence of idiosyncratic differences for length estimations, similar to those observed for perceptual judgments (Wolfe et al., 2005).

The insignificant gaze condition effect on step displacement contradicted the posed hypothesis that size estimates using step displacements would be more biased by the V-H illusion in TF and RTF conditions compared to MF condition and control trials. These findings are not consistent with a previous report showing biased average manual displacements according to the V-H illusion with gaze direction restricted (Yan & Honzinski, 2020). One obvious explanation for the non-significant results is linked to the two-visual-systems hypothesis, in which the action of step displacement differs from the perceptual judgments. However, we also consider another explanation, which links to the plane orientation of stimulus presentation relative to the plane orientation of movement. People actually altered step displacement according to the Müller-Lyer illusion (see Figure 5.8) when stepping without

vision occurred after viewing illusion presentation on the stepping surface (Glover & Dixon, 2004). People also produced greater vertical toe clearance ascending stairs (Elliott et al., 2009; Foster et al., 2015) or stepping over obstacles (Foster et al., 2016) when presented with multiple vertical segments on the vertical surface of stair or obstacle, respectively. In contrast, people in the present study viewed vertically oriented stimuli and performed step displacements on the horizontal surface of the ground. These outcomes may correspond better to manual control in the horizontal plane in which accuracy of goal-directed hand movements on a horizontal surface differs from the accuracy of goal-directed hand movements on vertical surfaces, the surface of stimulus presentation (Dalecki et al., 2019). The general biases according to illusory influences may exist for conditions when movement displacements align with the direction of stimulus presentation. Illusory influences on lower limb movement may only occur when the stimulus and movement displacement are in parallel planes. Future studies are warranted to test this hypothesis.

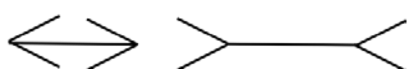

Figure 5.8. Müller-Lyer illusion. People usually underestimate perceived line length with the wings-in (left) and overestimate line length with wings-out (right) (Porac, 1994).

Anticipatory postural adjustments

COPamp and COPtime were evaluated as APA variables associated with the motor planning phase of stepping (Burleigh-Jacobs, Horak, Nutt, & Obeso, 1997; MannHagy, White, & Liddell, 1979; Ruget et al., 2008). Increases in APA durations often accompany worse balance (Remelius et al., 2008; Ruhe et al., 2011), in which people with Parkinson’s disease are less capable of generating a fast COP displacement (Baratto, Morasso, Re, & Spada, 2002). The

greater COPtime in TF and RTF conditions demonstrated greater APA durations, especially for the short configuration (see Figure 5.6B), indicating potentially greater imbalance in these conditions. Furthermore, relatively small COP amplitudes prior to the step initiation occur in people with neurological impairments, such as multiple sclerosis (Remelius et al., 2008; Ruhe et al., 2011) and Parkinson's disease (Mancini, Zampieri, Carlson-Kuhta, Chiari, & Horak, 2009) to suggest alterations in movement planning that differ from healthy controls. Although participants in the present study were not neurologically impaired, they did produce smaller COPamp in MF condition compared to TF and RTF conditions. We reasoned that task requirements of estimating bisecting segment lengths when able to view the movement differed from planning in the TF and RTF conditions, in which viewing was restricted away from the movement. Furthermore, unlike others (Zettel, Holbeche, McIlroy, & Maki, 2005; Zettel, McIlroy, & Maki, 2002), APAs were not correlated with step displacement in this study. It appears logical to suggest that APAs used for estimating segment lengths, thus proactive stepping, would differ from APAs used for reactive stepping.

Propulsive forces and peak velocity

Peak velocity of the stepping movement was influenced by configuration size and gaze condition. ANOVA and correlation results revealed that greater peak velocities associated with faster movements for long configurations which surpassed the slower peak velocities for short configurations and corresponded to step displacement results to support evidence revealing that greater peak velocities occur with larger movement excursions (Bahill, Clark, & Stark, 1975; Newell, Hancock, & Robertson, 1984; Pfann, Buchman, Comella, & Corcos, 2001). Of greater interest in the present study is the evidence which revealed that smaller peak velocities existed for MF compared to TF and RTF conditions, yet did not for step displacements. The inability to

view the limb and target during movement in TF and RTF, which can improve movement accuracy (Beaubaton & Hay, 1986), likely created less certainty during task preparation. The faster stepping when confidence is low during movement planning, observed elsewhere, may be linked to greater balance control (Sun, Guerra, & Shea, 2015). COPtime results for TF and RTF conditions support this low balance confidence possibility. The fact that we observed smaller peak velocity in the MF condition would suggest the potential for use of greater visual feedback (Khan & Franks, 2000) for stepping, balance control (Baratto et al., 2002), and in this case a false sense of movement accuracy.

Results for normalized peak vertical ground reaction force amplitude mimicked those for peak velocity to suggest an association between the two. Participants produced greater vertical ground reaction force amplitudes for long configurations and longer step displacements compared to the shorter counterparts similar to elsewhere (Frederick & Hagy, 1986). Our findings also compare similarly to hand movements in which greater grasping force (Jackson & Shaw, 2000) and lifting force (Brenner & Smeets, 1996) accompanied larger sized objects. Similar to PV, gaze condition effects on normalized peak vertical ground reaction force amplitude did not exist for step displacement; however, unlike PV, correlative relationships between step displacement and normalized peak vertical ground reaction force amplitude also did not exist across participants. We use the discussion in the next section to address these seemingly contradicting outcomes.

Motor planning verses motor execution

We found evidence to support the use of V-H illusion influences on perceptual judgments in our participants in each of the gaze conditions. This is not surprising considering that viewing stimuli were the same for perceptual judgments across gaze

conditions. We also found evidence to support allowing people to look down during movement (MF) resulted in different anticipatory postural adjustments, peak velocity, and vertical ground reaction forces and similar length estimations using step displacements compared to restricting gaze away from movements (TF and RTF). Providing participants with the ability to look down during the movement altered the planning of the step and early step execution through approximately the first half of the movement but not the final performance. These findings seem to support the planning-control model in which illusory effects on movement decay overtime due to online corrections (Glover & Dixon, 2001). Although our data do not support consistent illusory influences on performances across participants in this study (Figure 5.4), this may be linked to the poor performance of length estimations, thus greater errors using step displacements that occur with separate planes of stimulus presentation and movement (Dalecki et al., 2019). We postulated that the potential distorted illusory effect during the required sensorimotor transformations and plane transfer process may still decay with online feedback of movement allowed in the MF condition.

CONCLUSION

The longer and shorter length estimations using step displacement across gaze conditions differed from longer bisection influences on perceptual judgments to reveal support for a dissociation between perception and action. We concluded that exploitation of simple deceptive visual cues in a vertical plane which may guide movement planning and early movement execution do not guide horizontal plane stepping movements of the lower limb according to the V-H illusory influences.

CHAPTER 6. CONCLUSIONS

The focus of this dissertation was to explore the existence of potential V-H illusory influences on motor control. We assessed perceptual judgments and perceptuomotor control for length estimations using the upper (Studies 1 and 2) and lower (Study 3) limbs. Results were used to determine potential similar or different visual influences on perception and action to better understand underlying control mechanisms.

KEY RESULTS

Study 1 (Chapter 3) was designed to determine the effects of illusory-like configurations on perceptuomotor control. We examined the potentially deceptive influences of the vertical-horizontal (V-H) illusion-like configurations on manual length estimations made toward or away from various V-H configuration intersections. The use of various configuration types of the V-H illusion helped us understand that the use of the inverted T (IT) produced the strongest illusion effect to support the use of bisection (Finger & Spelt, 1947; Gavilán, Rivera, Guasch, Demestre, & García-Albea, 2017; Wolfe, Maloney, & Tam, 2005) and visual field (Künnapas, 1955a; Künnapas, 1955b; Künnapas, 1957a; Künnapas, 1957b; Künnapas, 1957c; Prinzmetal & Gettleman, 1993) influences. Reductions in perceptual responses with rotation of the configuration (Gavilán et al., 2017) were also found in manual length estimates only for conditions in which participants started the manual estimation at the IT intersection to suggest support for gaze fixation or direction influences on perceptuomotor control for this configuration. This latter finding was in line with a recent work in which researchers examined gaze fixation effects on perceptual judgments but not perceptuomotor control (Chouinard et

al., 2017). The results from study 1 prompted the use of only IT in study 2, in which we were able to test the potential gaze direction effect on movement, directly.

In study 2 (Chapter 4), we examined whether potentially deceptive influences of the IT V-H illusion on manual length estimations varied by gaze directions. The V-H illusory effect on manual length estimations strengthened with gaze directed on the IT configuration or the movement area in which the V-H illusion was presented in the same plane of movement in the near peripheral field. Results revealed support for gaze direction effects on perceptuomotor control of the upper limb and that it was probably gaze direction, rather than gaze fixation, that produced similar results to those for perception (Chouinard et al., 2017). The results from study 2 prompted the application of potential gaze direction influences on movement of the lower limb.

In study 3 (Chapter 5), we examined whether potentially deceptive influences of the IT V-H illusion on step length estimations varied by gaze direction. The primary goal was to determine whether length estimations using step displacements were influenced by vertical presentations of the V-H illusion when directing gaze on the configuration, the remembered configuration, or on the movement during performance. Movement planning and early movement execution did vary for different gaze restrictions, while step displacement did not, to suggest support for the planning-control model in which illusory influences decayed with time (Glover & Dixon, 2001).

COMPARISONS ACROSS STUDIES

The three perceptuomotor studies in this dissertation provide insight into the relationships between V-H illusory influences and motor control. Participants in each study were instructed to provide perceptual judgments on segment lengths of V-H illusory configurations, which required

cognition. In general, most participants' perceptual judgments on segment length, thus their interpretation abilities, were deceived by this illusion (Finger & Spelt, 1947; Charras & Lupiáñez, 2010). The V-H illusory influences on perceptual judgment differed for various illusions based on configuration type and orientation (Bruno et al., 2008).

Allowing participants to look wherever they wanted when performing manual length estimations did not always produce the same results within or across studies. Illusory influences did not exist for participants gazing freely for edge-center movements in study 1, in which the configuration was presented eccentric to movement, or in study 2. Gazing freely in the center-edge movement mode in study 1, in which participants started at the intersection of the V-H illusion, resulted in manual length estimations that matched expected illusory influences. We reasoned the differences may link to the fact that hand placement at the start of movement likely directed gaze toward the configuration during the center-edge movements. Directing gaze toward the V-H illusion produces greater illusory influences on perceptions (Chouinard et al., 2017) to support this idea.

We found evidence to support that, given the right parameters, exploitation of simple deceptive V-H illusory visual cues provided general guidance of upper limb movements in studies 1 and 2. In contrast, despite of application of gaze restrictions used in study 2, we found no evidence to support that this exploitation exists for general guidance of lower limb movements in study 3. Potential explanations for these results included less precision for lower limb than upper limb motor control (AI-Quraishi et al. 2018) or for different surface planes for stimulus presentation and movement (Dalecki et

al., 2019) or a combination of both. Future studies could be used to assess these possibilities.

SUMMARY

We found evidence that V-H illusion and illusion-like influences on movement did not always exist. Manual estimations of segment lengths were strongly influenced according to the V-H illusion when movement started on the V-H illusions (Study 1) or when gaze was restricted to IT configurations or the movement space (Study 2). Estimations of segment lengths were not influenced according the V-H illusions when manual start position was relatively far away from the intersection of the V-H illusion (Study 1), when people gazed freely (Study 2), and when using step displacements, located in a different plane than stimulus presentation, for estimations (Study 3). Together, these data emphasize the importance of gaze direction for movement executions of the upper limb and potential importance of stimuli presentation to enhance the general V-H illusory influences over motor control. The few significant within subject associations between length estimations and perceptual responses reveal a within subjects separation between visual control for perception and action associated with length estimations (Goodale & Milner, 1992).

FUTURE DIRECTIONS

The debate of whether the visual illusion influences on perception are supported by Goodale’s separated perception-action visual streams (Goodale, 2014; Goodale & Milner, 1992) is ongoing. The findings of this dissertation suggest that influences of the visual V-H illusion on motor control are altered/eliminated by certain movement and gaze directions and also revealed

that these effects on upper limb and lower limb vary. Several directions for future research are suggested below to provide greater insight into the perception-action relationship.

V-H studies have reported that people's visual perception on overestimating the bisecting segment in an IT was about 8.7%~16%, meaning that they perceived equal segments when lengthening the bisecting segment 8.7%~16. Although participants in those studies estimated the segment by providing an exact value showed deceived perceptual judgments, they did not produce a related body movement to estimate the segment length.

Although we compared perceptual and motor performance in study 2, our results were restricted to the use of categorical responses, thus limiting direct comparisons of illusory extent, which can be estimated more precisely (Mikellidou & Thompson, 2013). Determining a more exact measure of illusory extent would allow for a more detailed correlation analysis between perception and action.

In study 3, we found no V-H illusory influences over lower limb step displacements. Although we offered potential explanation of poor plane transferring abilities in people, future studies could be used to directly assess this possibility. We suggest an experiment involving same plane, parallel planes, and perpendicular plane presentations of illusory presentations and movements. Results could reveal that projecting the visual stimuli on the movement plane could influence length estimations using the lower limb. If true, applications of illusory influences could assist people with deficits in step displacements, like Parkinson's disease for example.

APPENDIX A. IRB APPROVAL FORMS

ACTION ON EXEMPTION APPROVAL REQUEST

LSU

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Shijun Yan
Kinesiology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: April 4, 2016

RE: **IRB#** E9865

TITLE: Illusory effects of the vertical-horizontal illusions on visual perception and body movements

New Protocol/Modification/Continuation: New Protocol

Review Date: 4/1/2016

Approved X **Disapproved** ____

Approval Date: 4/1/2016 **Approval Expiration Date:** 3/31/2019

Exemption Category/Paragraph: 2a; 2b

Signed Consent Waived?: No

Re-review frequency: (three years unless otherwise stated)

LSU Proposal Number (if applicable):

Protocol Matches Scope of Work in Grant proposal: (if applicable)

By: Dennis Landin, Chairman D Landin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: When emailing more than one recipient, make sure you use bcc. Approvals will automatically be closed by the IRB on the expiration date unless the PI requests a continuation.**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

ACTION ON PROTOCOL APPROVAL REQUEST

Dr. Dennis Landin, Chair
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TO: Jan Hondzinski
Kinesiology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: April 3, 2019

RE: **IRB#** 4212

TITLE: Estimating the length of a T configuration using upper or lower limb movements

New Protocol/Modification/Continuation: Modification

Brief Modification Description: Added post test questions to the data collection form.

Review type: Full ____ Expedited __X__ **Review date:** 4/3/2019

Risk Factor: Minimal __X__ Uncertain ______ Greater Than Minimal______

Approved __X__ **Disapproved** ______

Approval Date: 4/3/2019 **Approval Expiration Date:** 3/28/2020

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 100

LSU Proposal Number (if applicable):

By: Dennis Landin, Chairman ____*DLandin*____

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
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5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
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7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: Make sure you use bcc when emailing more than one recipient.**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

APPENDIX B. CONSENT FORMS

Louisiana State University—Department of Kinesiology—**Consent Form**

1. **Study Title:** Illusory Effects of Vertical-Horizontal Illusion on Gaze and Steps.
2. **Purpose of the Study:** The purpose of this investigation is to determine if differences in gaze and step distance exist while looking in various illusory configurations

   Study Procedures:

   The experiment will be made up of a perceptual task and a motor task. In the perceptual task you will report which segment in the figure looks longer (horizontal or vertical), or whether the two segments look equal. The motor task will consist of a single lateral step to match the length of a given stimulus. You will start standing with your feet side-by-side close together. Feet will be marked in this position by outlining them so starting position remains consistent for every trial. You will be shown a stimulus (i.e., a horizontal segment with or without a vertical segment attached) then asked to look at the end or intersection and take a small step forward to match the end of the horizontal segment or intersection of H-V segments followed by a lateral eye movement and step so that the corresponding distance on the horizontal line matches the vertical segment length.

   Reflective markers will be placed on the body to monitor body movement. A SMI eye tracker will be used to monitor fixations and eye movement distance.

   Withdrawal: There are no consequences if you choose to withdraw from participation at any time during this study.

   Removal: The investigators may remove you from the study for any number of reasons, including, but not limited to, the detection of adverse responses, the appraisal of health status, and technical difficulties in obtaining information during the testing session. If the investigators elect to remove you from the study they will provide you with the justification for doing so, and you will be given an opportunity to ask questions regarding your removal.
3. **Risks/Discomforts:** You will be asked to stand for periods of at least 2 minutes at a time while performing single-stepping movements. Low risks include muscular fatigue. The risk should be similar to that of performing stepping tasks required of your daily life. **Measures Taken to Reduce Risks:** The risk in this study will be minimized by proper evaluation, education, and treatment, careful testing prescription, and the presence of well-trained personnel capable of monitoring equipment. To minimize risk of muscle fatigue, you will be given opportunities to rest between trials. You may request additional rest if needed at any time during the study. You may also stop the testing at any time should you feel uncomfortable. **Unforeseeable Risks:** The risk of the project is minimal and various precautions are in place to avoid any possible unforeseeable risks.
4. **Benefits:** You will not receive any monetary compensation for your participation in this study. However, the information extracted from your participation will be beneficial to future studies and/or illusion related movement strategies regarding healthy adults.
5. **Alternatives:** The researchers encourage you to seek medical attention for your illness. There are predicted benefits for one to participate the project, but those benefits have not been proven due the experimental nature of the study.
6. **Investigators:** Are available for questions about the study M-F between 8:00 am and 4:30

pm
Dr. Jan Hondzinski: phone: 225-578-9144; e-mail: jhondz1@lsu.edu;
Shijun Yan: email: syan5@lsu.edu

7. **Performance Sites:** Data will be collected and training will be in Kinesiology Labs at Louisiana State University and Agricultural and Mechanical College
8. **Number of Subjects:** 100
9. **Subjects**
    a. **Inclusion Criteria:** A young adult at least 18 with fully intact sensation on your foot soles. You must be able to stand unassisted (i.e., without a cane or walker) for periods of at least 2 minutes and be able to step laterally.
    b. **Exclusion Criteria:** You will be excluded from this study if you have a history or evidence of central nervous system problems, musculoskeletal deformity, leg arthritis or pain that limit standing or weight bearing exercise, history or evidence of inner ear problems, history of chest pain, nausea, diaphoresis or shortness of breath with exercise, presence of foot ulcers, certain diseases (DM, Arthritis, Heart etc.), and/or cognitive impairment. You will be excluded from the study if you are pregnant. You will be excluded from this study if any of your lower extremities (i.e., legs, feet, toes) have been amputated. Visual acuity worse than 20/40 (that required for driving in the US).
10. **Right to Refuse:** You may withdraw from the study at any time without penalty or loss of any benefit to which you are otherwise entitled.
11. **Privacy:** Every effort will be made to maintain your privacy through confidentiality. You will be assigned a number for identification in the study and all information you provide during the study will be coded by that number. Files will be kept in a secure room to which only university personnel have access. The results of the study may be published, but no names or identifying information will be included in the publication. Your identity will remain confidential unless disclosure is required by law.
12. **Signatures:** The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. For injury or illness, call your physician, or the Student Health Center if you are an LSU student. If I have questions about subjects' rights or other concerns, I can contact Dennis Landin, Institutional Review Board, (225) 578-8692, irb@lsu.edu, or www.lsu.edu/research. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

Subject Signature ______________________________ Date _________________

13. **For research involving the collection of identifiable private information or identifiable biospecimens one of the following must be listed on the consent form:**
    Identifiers might be removed from the identifiable private information. After removal, the information may be used for future research studies or distributed to another investigator for future research studies without additional informed consent.

    Yes, I give permission _________________________________
    Signature
    No, I do not give permission _________________________________
    Signature

1. Study Title: Estimating the Length of a T Configuration Using Upper or Lower Limb Movements

2. The purpose of this study is to investigate the accuracy of length estimating movements associated with different sizes of and/or different orientations of an inverted T configuration of different sizes. You will either perform a reaching task or a stepping task. First, you will be asked to read and sign the informed consent after any questions and concerns about the study are answered. You will respond to a set of questions to obtain descriptive characteristics and to ensure you meet the inclusion criteria for the study. Weight, height, and visual acuity will be measured and recorded. You will view an inverted T configuration with the segments of different or equal lengths. After viewing a configuration, you will orally respond which segment appears longer by saying "VERTICAL", "HORIZONTAL" or "EQUAL". This will occur prior to the movement.

3. Risks: The study presents no known direct risk to you beyond those associated with reaching while seated or standing still for minutes at a time. There is an inadvertent risk concerning anonymity. However, every effort will be made to ensure strict confidentiality. All data and participant information will be kept in a locked cabinet in a locked room and on a password-protected computer.

4. Benefits: You may receive extra credit in a course if pre-arranged; however, no other direct benefits will be offered.

5. Alternatives (if applicable): It is specified whether there are proven, established treatment options available that may be advantageous to the subject (in lieu of the study treatment).

6. Investigators: The following investigators are available for questions about this study, M-F, 8:00 a.m. - 4:30p.m., Shijun Yan, 225-6206125; Dr. Jan Hondzinski, 225-578-9144.

7. Performance Site: Kinesiology labs in the HP Long Field House, Louisiana State University and Agricultural and Mechanical College

8. Number of subjects: 100

9. Subject Inclusion: Young adults from the Baton Rouge area, ages of 18 to 39 years old able to perform the tasks described below. Impairment in visual acuity with or without the use of corrective lenses. Most glasses do not work well with the eye tracker, so wear contacts, if needed. (i.e. Snellen test values greater than 20/40, the score needed to read U.S. road signs from far enough away to be able to make adequate decisions and perform proper responses (Owsley and McGwin 2010)), Any use of pharmaceuticals that could interfere with postural control, the presence of musculoskeletal and/or neuromuscular impairments in the previous 6 months would prevent the performance of the required tasks. To participate in this study, you must meet the requirements of both the inclusion and exclusion criteria.

10. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.

11. Privacy: Results of the study may be published; however, no names or identifying information will be included. Identities will remain confidential unless discloser is legally required. Data will remain confidential as well unless compelled by law.

12. Signatures:
The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. For injury or illness, call your physician, or the Student Health Center if you are an LSU student. If I have questions about subjects' rights or other concerns, I can contact Dennis Landin, Institutional Review Board, (225) 578-8692, irb@lsu.edu, or www.lsu.edu/research. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

Subject Signature: ________________________________ Date: ________________

The study subject has indicated to me that he/she is unable to read. I certify that I have read this consent form to the subject and explained that by completing the signature line above, the subject has agreed to participate.

Signature of Reader: _______________________________ Date: _______________

13. For research involving the collection of identifiable private information or identifiable biospecimens one of the following must be listed on the consent form:

Identifiers might be removed from the identifiable private information or identifiable biospecimens. After removal, the information or biospecimens may be used for future research studies or distributed to another investigator for future research studies without additional informed consent.

Yes, I give permission____
Signature

No, I do not give permission____
Signature

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