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Müller-Lyer Illusion Effect on a Reaching Movement in Simultaneous Presentation of Visual and Haptic/Kinesthetic Cues

Masayuki Hara, *Member, IEEE*, Sho Kosaka, Jian Huang, *Senior Member, IEEE*,
Hannes Bleuler, *Member, IEEE*, and Tetsuro Yabuta, *Senior Member, IEEE*

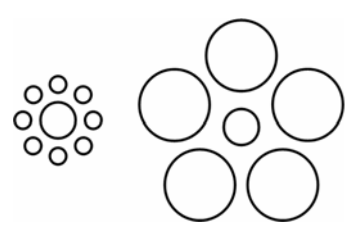
Abstract—**This paper describes the effect of Müller-Lyer illusion on a reaching movement just after the visual and haptic/kinesthetic cues are simultaneously presented. First, a standard experiment on this visual illusion is conducted by means of the most typical way so as to make sure that participants can experience this illusion; the result shows that all the subjects are deceived by the illusion figure as in many previous results. As the next step, the subjects are asked to physically trace one of three lines—normal line and lines with feathers of an arrow—with the same length displayed on an LCD. After a few traces, the line suddenly vanishes, and then the subjects retrace the invisible line based on only their memory and somatic sensations. During this task, we measure the trajectory of fingertip from a start to the goal using a motion capture system. The result indicates that the Müller-Lyer illusion dominantly affects the reaching task although the haptic/kinesthetic cue was also given just before the task. Thus, this result implies that the visual illusion affects the motion planning, which partly supports a planning-motion model.**

I. Introduction

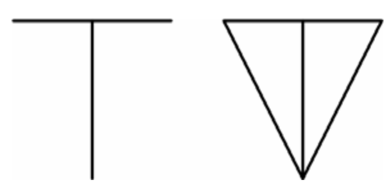
In our daily lives, human beings can unconsciously perform the dexterous movement by skillfully using their own upper limbs. For example, children can easily pick up a candy located in front of them. At this time, they determine one behavior without especially calculating the optimized path in the brain although there exist countless paths from the body to the candy. It is supposed that the flexible body and high-order system in our brains for the motion control enable such natural movements. Regarding the movement of upper limb, many researchers have focused on the reaching movement and tried to propose the movement model, such as the minimum jerk model [1] and minimum torque-change model [2]. However, since human system is so complicated, most of the principle has not been revealed yet. Hence, identifying the movement principles of upper limb is a very attractive theme.

In our previous studies, we have attempted to examine how human beings produce dexterous behaviors by using a motion capture system so as to emulate human-like movements in a finger-arm robot system [3][4]. In particular, our studies have focused on the human manipulability, which is a standard index that shows the mobility of multi-joint robots [5]. In addition, as the other trial, we also attempted to provide some haptic illusions, such as the size-weight illusion (Charpentier effect), in virtual reality by using haptic devices [6]. Based on these studies, we have got interested in how visual illusions affect human behaviors and motion control.

As for the effect of visual illusions on human actions, many researchers have debated how to explain the pattern of it. For example, Rudel et al. attempted to examine how the effect of visual and haptic illusions decrease with repeated trials by using the Müller-Lyer illusion figure [7]. Aglioti et al. tried to reveal the effect of Tichener size-contrast illusion (see Fig. 1 (a)) on the maximum grip aperture in a grasping [8]; their results showed that the Tichener size-contract illusion more affected perceptual judgment than the grip aperture. Vishton et al. suggested that a three-fingered grasp of a two-dimensional triangular figure (see Fig. 1 (b)) was susceptible to the horizontal-vertical illusion [9]. Recently, Carey reviewed several studies on visual illusions and actions [10]. According to his review, most studies suggested that visual illusions do not affect human behaviors as much as human perceptions—perception-action model [11]. In addition, some studies have insisted that our behaviors are strongly affected by visual illusions in the early stage than in the later stage during the movement—dynamic illusion effect [12]. Based on the idea of the dynamic illusion effect, Glover suggested that the visual illusion affects the motion planning



(a) Tichener size-contrast illusion



(b) Horizontal-vertical illusion (Wundt-Fick illusion)

Fig. 1. Visual illusion figures used in previous studies.

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M. Hara and H. Bleuler are with Ecole Polytechnique Fédérale de Lausanne, Lausanne, 1015 Switzerland (phone: +41 21 693 59 47, e-mail: masayuki.hara@epfl.ch, hannes.bleuler@epfl.ch).

S. Kosaka and T. Yabuta are with Department of Mechanical Engineering, Yokohama National University, Yokohama, 240-8501 Japan (e-mail: kosaka@yabsv.jks.ynu.ac.jp, yabuta@ynu.ac.jp).

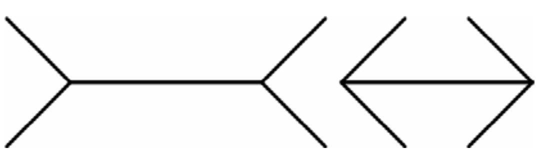
J. Huang is with Department of Intelligent Mechanical Engineering, School of Engineering, Kinki University, Higashi-Hiroshima, 739-2116 Japan (e-mail: huang@hiro.kindai.ac.jp).

but not the motion control—planning-control model [13]. His suggestion is quite attractive, however he only discussed it in the paper using the results of recent studies on the effect of visual illusions on human actions. Hence, we need to verify the validity of his proposal experimentally.

The goal of this study is to reveal the interactive relationships between the human cognition and motion control under unique conditions, and to apply the identified characteristics to multimedia services and robotic controls. This paper, in particular, focuses on the Müller-Lyer illusion effect on a reaching movement by the upper limb when the visual and haptic/kinesthetic cues are simultaneously presented just before the task; very few studies have argued the effect of visual illusion under such a condition. Through the experiment with a motion capture system, we discuss whether the planning-control model is correct or not.

II. Müller-Lyer Illusion

The Müller-Lyer illusion is one of the most famous and oldest visual illusions, which was discovered more than 100 years ago [14]. Fig. 2 (a) shows a typical variation of the Müller-Lyer illusion figure consisting of lines with feathers of an arrow. As demonstrating in Fig. 2 (a), people usually claim that the two lines have different lengths when asked to compare the lengths of the two lines although the two lines have the same length; in this case, the line with inward arrows (feathers) on the left side should be perceived to be longer compared to the line with outward arrows (arrows) on the right side. It is widely believed that the Müller-Lyer illusion is related to our cognition for the three-dimensional space; as for this principle, much debate has arisen. One possible explanation for this illusion is that people might see the two lines as the three-dimensional figure such as stairs, as shown in Fig. 2 (b) [15][16]. We empirically know that the distant object is larger than the nearby object if they are visually the same. Hence, in Fig. 2 (b), it is considered that our visual system detects the depth cues, which are related to three-dimensional space, from the two-dimensional deformed figure and our brain unconsciously tries to correct the nearby line to be shorter even if the two lengths are visually recognized to be the same. In this paper, we focus on this Müller-Lyer illusion and examine how human beings perform the reaching movement under the visual illusion influence.



(a) Deformed figure (with the same length)

(b) Müller-Lyer illusion in a real environment

Fig. 2. Müller-Lyer illusion figure.

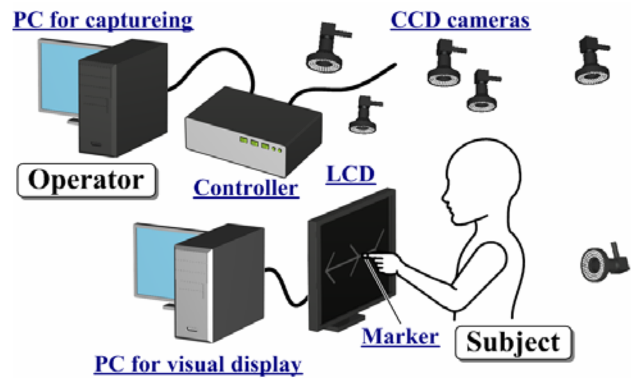


Fig. 3. Schematic diagram of experimental system.

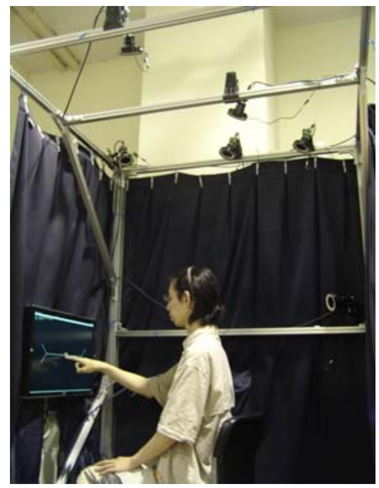


Fig. 4. Experimental environment.

III. Motion Capture System

Figs. 3 and 4 are a schematic diagram of a motion capture system and a picture of the experimental environment, respectively. In order to measure the trajectory of an index finger, a three-dimensional real-time tracking system (model: PRO-Tracker II, DITECT Co., Ltd) was employed in this study, whose capturing performance is 60 fps. The motion-capturing-enabled space surrounded by blackout curtains has 2 m in height and 1.5 m in width and depth; subjects can freely move their upper limbs in this space. As shown in Fig. 3, six CCD cameras (model: XC-HR57, Sony) are located on the upper frame above the subject. Basically, it is sufficient in the use of two cameras to measure the fingertip movement because a reflective marker on the index finger has only to be captured in this experiment. However, six cameras were employed to avoid the occlusion as far as possible. Further, this is for our future study, in which we will enable the motion capturing of the whole behavior of upper limb and attempt to examine the effect of manipulability and so on.

As for displaying the Müller-Lyer illusion figure, we exhibited the figures on a 24-inches-wide liquid crystal display (LCD) located in front of the subject; the two-dimensional graphics is provided by a different computer from that for the motion capturing. Further, a GUI-enabled application is programmed for this experiment. In this application, the operator, who conducts the experiment, can easily and quickly change the characteristics of visual illusion figures by a few keystrokes. The operator can also observe the trajectory of a reflective marker on the index finger.

IV. Preliminary Experiment

A. Experimental Conditions

Before examining the effect of the Müller-Lyer illusion on the reaching movement, we confirmed that the subjects can visually experience the Müller-Lyer illusion. As used in many previous studies, two figures—arrow-feather type and feather-arrow type—as shown in Fig. 5 were used; the extent of the line on the right side was variable based on the center and the arrowheads are bent at 45 deg in this study. Further, subjects could freely change the variable length using a game pad, as shown in Fig. 6. In this experiment, seven subjects were asked to freely extend or shorten the variable length until they subjectively regarded the two lengths on the right and left sides as the same; after the subjects stopped the adjustment, the adjusted length was recorded in each trial. The initial value of the variable length was randomly displayed from 50 to 150% of the standard length—100 or 150 mm—at the rate of 25%. Finally, 10 patterns of visual stimuli, including 2 patterns in the standard length and 5 patterns in the initial length, were randomly presented to the subjects in each figure type.

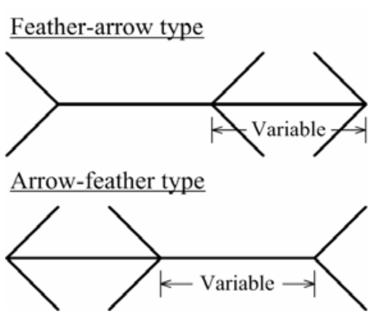
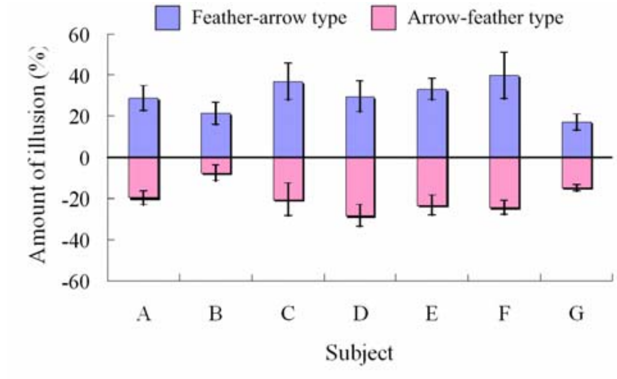
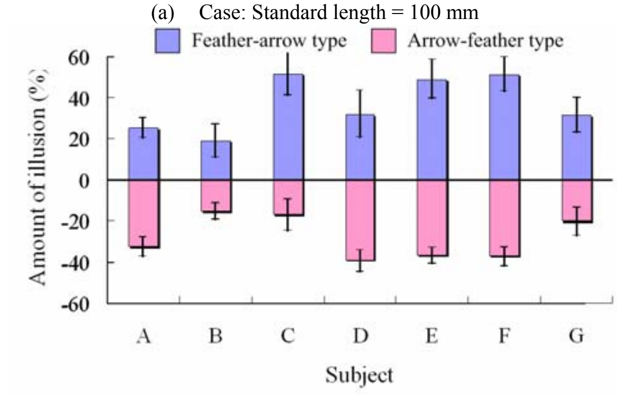


Fig. 5. Müller-Lyer illusion figure used in preliminary experiment.

Fig. 6. Standard Müller-Lyer illusion experiment.



(a) Case: Standard length = 100 mm



(b) Case: Standard length = 150 mm

Fig. 7. Averaged amount of the visual illusion.

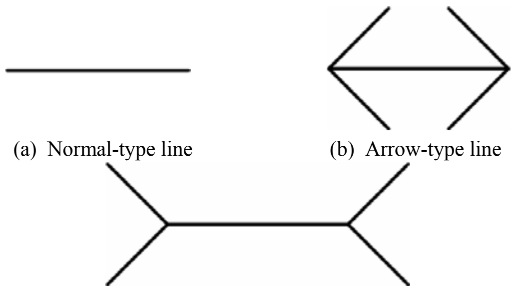
B. Verification of the Müller-Lyer Illusion

Fig. 7 (a) and (b) show the results under the conditions of 100 and 150 mm standard lengths, respectively. In Fig. 7, the blue and red bars show the averaged amounts of illusion, which represent the evaluation of the variable length to the standard length, in the feather-arrow and arrow-feather types, respectively. For example, in the case of feather-arrow type, the amount of illusion must be a positive value if the visual illusion is caused. This is because the line with feathers is perceived to be longer than the line with arrows. Thus, the variable length should be adjusted to be longer than the standard length so as to subjectively make them the same. Here, it should be noted that all the subjects estimated that the line with feathers was longer in comparison to the line with arrows in any conditions. This means that all the subjects experienced the standard Müller-Lyer illusion visually. The approximate amount of illusion is 30% of the standard length although there were some individual differences. Hence, this experiment also verified that our visual display enables all the participants to experience the Müller-Lyer illusion.

V. Müller-Lyer Illusion Effect on Reaching Task

A. Experimental Scheme

As the next step, we examined the effect of the Müller-Lyer illusion on the reaching movement for the seven subjects, who were the same in the experiment in chapter IV. In this



(a) Normal-type line (b) Arrow-type line

(c) Feather-type line

Fig. 8. Visual stimuli displayed during the reaching movement.

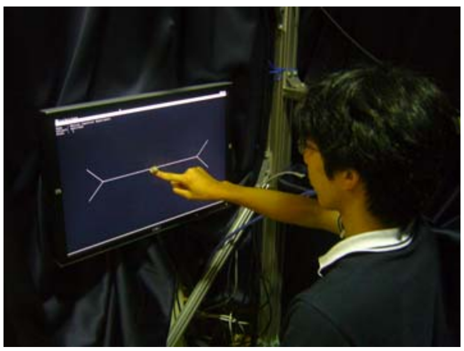


Fig. 9. Tracing the line displayed on the LCD.

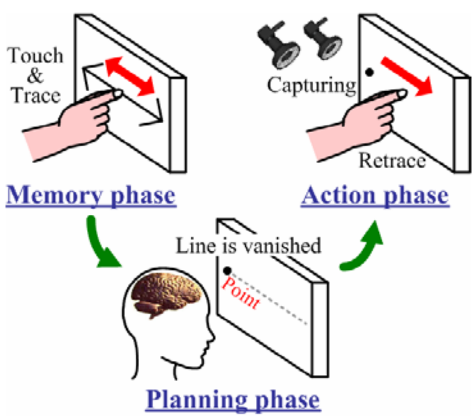
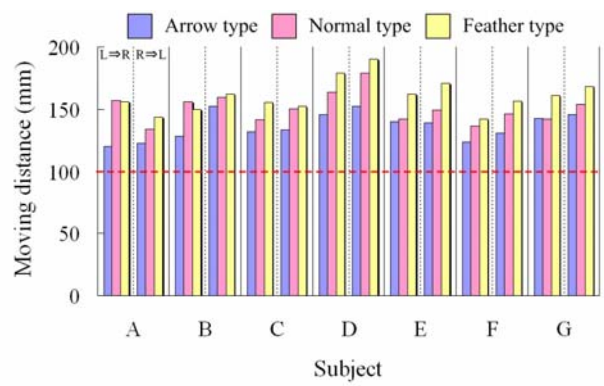


Fig. 10. Schematic diagram of experimental procedure.

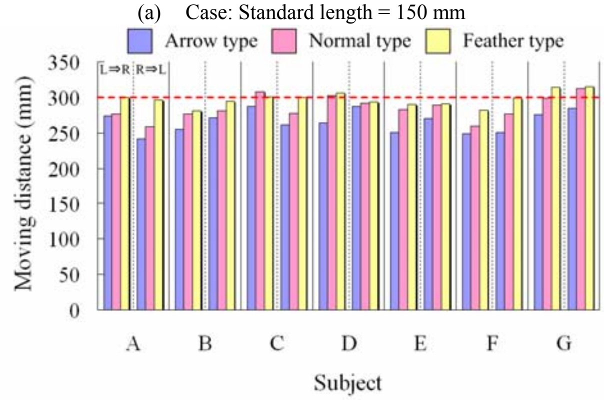
experiment, we displayed one of the three lines, as shown in Fig. 8, in the horizontal or vertical direction on the LCD and asked the subjects to trace the line, as shown in Fig. 9. Fig. 10 shows a schematic diagram of experimental procedure; it is assumed that there are three phases in the procedure. First, the subjects physically touched and traced the line displayed on the LCD. At this time, they memorized the extent of the line based on the visual and haptic/kinesthetic cues. After a few tracings, the figure completely disappeared and a starting point was displayed at a random position instead. Then, the subjects started to retrace the invisible line from the starting point using somatic sensations, i.e., the subjects had to find the goal point only based on their memories. During the movement, the trajectory of a reflective marker on their index fingers from a start to the end of the motion was measured by using the motion capture system described in chapter II. Before the experiment, we conducted a very simple test for categorizing the subjects as the right-handed, the left-handed, and the both-handed. According to the results, one of the seven subjects, referred as subject B in following results, was both-handed; the others were right-handed. Hence, we instructed the subjects to use their right index fingers for perceiving the extent. The three lines—normal-type line, arrow-type line, and feather-type line—in Fig. 8 were respectively presented to the subjects 5 times at random. In this experiment, the standard length was set at 150 or 300 mm. Further, the subjects were asked to retrace the line rightward and leftward due to the starting point to reveal the influence of moving direction; the subjects totally performed 30 trials.

B. Reaching Movement in the Horizontal direction

Fig. 11 (a) and (b) show the results when the subjects performed the reaching movement toward the right and left directions, respectively. In Fig. 11, the blue, red, and yellow bars are the representative distances, which are averaged over 5 trials, from a start to the end of the reaching movement when the subjects retraced the feather-type line, normal-type line, and arrow-type line just after the figures were vanished, respectively. Here, the averaged distance when the subjects retraced the normal-type line without visual cues is regarded as a neutral result. Comparing the results of the arrow-type line and feather-type line, it should be noted that all the subjects performed the reaching movement longer after seeing and tracing the feather-type line, whereas the moving



(a) Case: Standard length = 150 mm



(b) Case: Standard length = 300 mm

Fig. 11. Relationships between the displayed line and the moving distance in the horizontal direction.

TABLE I
EVALUATIONS BY ANOVA (HORIZONTAL DIRECTION)

VF	*SS*	*df*	*MS*	*F*	*P* (%)
Case: Standard length = 150 mm					
A: Line type	20864	1	20864	100.008	0.006
error	1252	6	209		
B: Direction	1230	1	1230	4.285	8.388
error	1722	6	287		
C: Trial num	1503	4	376	1.478	23.994
error	6100	24	254		
AB:	5	1	5	0.041	84.662
error	703	6	117		
BC:	270	4	68	0.573	68.495
error	2831	24	118		
CA:	97	4	24	0.115	97.599
error	5072	24	211		
ABC:	364	4	91	1.253	31.562
error	1741	24	73		
Total	57612	139			
Case: Standard length = 300 mm					
A: Line type	34620	1	34620	136.426	0.002
error	1523	6	254		
B: Direction	122	1	122	0.158	70.476
error	4636	6	773		
C: Trial	2470	4	617	1.929	13.815
error	7681	24	320		
AB:	2	1	2	0.002	96.445
error	4302	6	717		
BC:	155	4	39	0.179	94.724
error	5214	24	217		
CA:	1394	4	348	1.218	32.910
error	6863	24	286		
ABC:	558	4	139	0.332	85.384
error	10088	24	420		
Total	90352	139			

VF: Variable factor, *SS*: Sum of squares, *df*: Degree of freedom
MS: Mean square, *F*: F-value, *P*: Probability of observed F-value

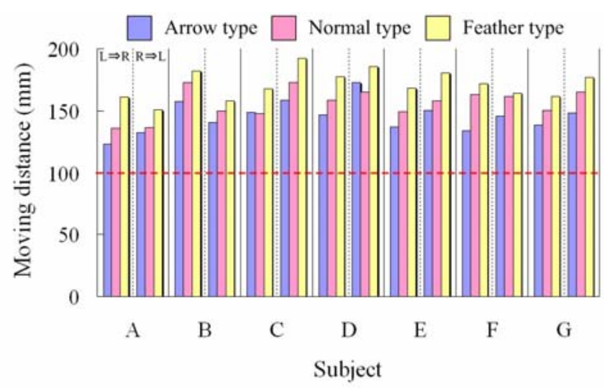
distance became shorter in the case of the arrow-type line. This means that the Müller-Lyer illusion caused some influence on the reaching movement, although the subjects also know the extent of line physically. Further, this result indicates that the moving direction is almost nothing to do with the performance. Here, a three-way analysis of variance (ANOVA) was conducted for the results of the arrow-type line and feather-type line so as to statistically examine the difference between the two results, whose variable factors are the line type, moving direction, and trial number. Table I lists the results of ANOVA. Focusing on the result in the line type, the null hypothesis that there is no significant difference between the two results can be rejected because the probability of observed F-value is below the 1% level of significance ($P<0.001$) in each standard length condition. This implies that there exists the significant difference between the two results. Further, Table I also indicates that the moving direction did not relate to the performance.

Hence, these results indicate that the subjects overestimated the length of line when the feather-type line had been displayed just before the reaching movement, whereas the length was underestimated when the arrow-type had been displayed. That is, these results imply that the Müller-Lyer illusion affected the reaching movement, in particular, the planning phase of the motion because any visual cues but a starting point was not displayed during the final reaching movement. Therefore, our results may experimentally support a part of the Glover's proposal [13] in which the visual illusion affects the motion planning.

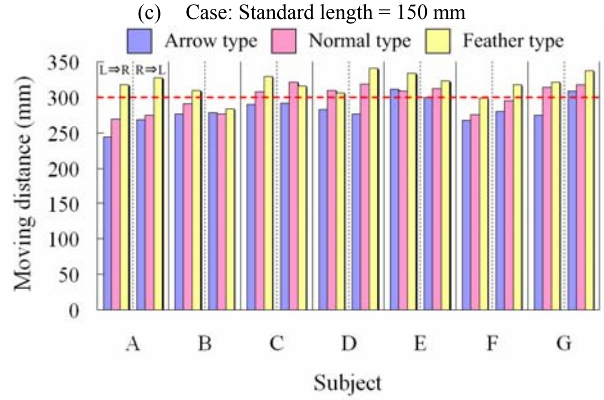
C. Gravity Effect

In order to examine the gravity effect, we also asked the subjects to perform the same task in section *A* in the vertical direction. Fig. 12 shows the relationships between the displayed line and the moving distance in the vertical direction. Similar to the results in Fig. 11, the moving distance became longer when the subjects retraced the feather-type line after seeing and tracing it; its ANOVA also indicates the significant difference between the two results although this paper does not show the result. Thus, these results demonstrate that the Müller-Lyer illusion also affected the reaching movement in the vertical direction.

Here, let's try to consider whether or not the gravity affects human behavior based on the Müller-Lyer illusion. Table II lists a comparison of the results in the horizontal and vertical directions. It should be noted that the averaged moving distance becomes relatively longer when the reaching movement is performed in the vertical direction; this implies the effect of the gravity. However, it should be also noted that in the vertical movement, the averaged moving distance is almost the same in both the directions or slightly longer when the reaching movement is performed upward. If the gravity affects the reaching movement, the upward movement should



(c) Case: Standard length = 150 mm



(d) Case: Standard length = 300 mm

Fig. 12. Relationships between the displayed line and the moving distance in the vertical direction.

TABLE II
AVERAGED MOVING DISTANCES

Type	Horizontal direction		Vertical direction	
	Rightward	Leftward	Downward	Upward
Case: Standard length = 150 mm				
Arrow	133.2	139.5	140.9	149.7
Normal	148.4	153.2	154.0	158.6
Feather	158.0	163.7	170.1	172.8
Case: Standard length = 300 mm				
Arrow	265.1	266.8	278.4	286.2
Normal	286.4	283.9	296.7	302.4
Feather	296.3	298.4	316.7	321.0

Unit: mm

be shorter because the gravity would act to disturb it; on the contrary, the downward movement should be longer because the gravity would act to assist it. Thus, this fact implies not only the gravity effect but also the effect of other factors.

Regarding this, one possible reason is that the subjects unconsciously estimated the gravity effect; they might output the motor command with the gravity compensation. From another viewpoint, the effect of horizontal-vertical illusion shown in Fig. 1 (b) might be considered. Generally, human beings tend to visually perceive the vertical extent to be longer than the horizontal extent. Hence, not only the Müller-Lyer illusion but also the horizontal-vertical illusion affects the motion planning. Since this phenomenon is quite attractive, we will further examine it in the future studies.

VI. CONCLUSION

This paper described how the visual illusion, in particular, the Müller-Lyer illusion affects human behavior. In our experiment, the subjects were asked to trace a line with one of three shapes and memorize the length. After that, the subjects retraced the invisible line using their memories and somatic sensations. During the task, the movement of index finger was observed using a motion capture system. The results and statistical analysis demonstrated that the Müller-Lyer illusion obviously affected their reaching movements. This is a very attractive result because the illusion-based visual cue strongly affected human behavior, although the haptic/kinesthetic cue was also presented just before the task. On the other hand, the moving direction was irrelevant to the moving distance. These results also imply that the Müller-Lyer illusion affected the motion planning because any visual cues but a starting point was not available during the retracing task. This result may partly support the Glover's proposal. In addition to this, we discuss the gravity effect on this phenomenon. According to the result, not only the gravity but also other factors seem to affect human behavior in this case. With regard to this, we should make the reason clear in the future studies.

This paper shows an interaction between the vision and kinesthesia as a first stage. In the future studies, we will try to examine how the sensorimotor system works under the illusion and where the subjects gaze during the task by using an eyes-tracker system; we are now trying it. In addition to this, we aim to provide novel applications in multimedia service by using the interactive characteristics.

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