SICE Annual Conference 2013
September 14-17, 2013, Nagoya University, Nagoya, Japan

An experimental investigation of changes to visual size perception in conjunction with motor learning in a line tracing task

Satoshi Ito[1] Taisei Hidaka[1] Shingo Nishio[1]
Minoru Sasaki[1] Mohammad Darainy[2,3] and David J. Ostry[2,4]
[1]Department of Engineering, Gifu University, Gifu, Japan
(Tel: +81-58-293-2540; E-mail: ics@gifu-u.ac.jp)
[2] McGill University, Montreal, Canada
[3] Shahed University, Tehran, Iran
[4]Haskins Laboratories, New Haven, Connecticut, USA

Abstract: In this paper, we investigate whether motor learning affects visual size perception in humans. Our hypothesis is that motor learning tasks requiring precise manipulation or careful control of movement increase visual size perception. As a motor learning task, a line tracing manipulation involving fine position control of the hand was selected. By presenting horizontal or vertical bars at a variety of different widths, we were able to test for changes in visual size perception by examining subjects before and after the line tracing task. The results indicate that a horizontal bar looks thicker to the subjects after horizontal line tracing and a vertical bar looks thicker after vertical line tracing. Motor learning is thus accompanied by changes to visual perception.

Keywords: motor learning, reaching movement, visual perception, line trace, thickness recognition

1. INTRODUCTION

There are aspects of human perception that involve relative evaluation. A good example can be found in air temperature sensations: 20 degrees Celsius feels mild in the spring, but cool in the autumn. This suggests that sensory processing is not fixed. There is ongoing sensory adaptation.

Recently, examples of sensory adaptation has been observed in the context of limb movement. Some papers [1, 2] report that the visuomotor mapping is recalibrated in situations in which visual and somatosensory perception are mismatched in arm reaching tasks. It was also demonstrated that somatosensory perception changes under the force field learning conditions during arm reaching movements [3]. However, motor learning may affect not only somatosensory perception but also visual perception. Brown et. al [4] demonstrated that the predicted motion of a visual target is altered in the context of force field learning. Witt and Dorsh [5] report that motor performance affects size recognition, in particular the size of the goal in American football players.

These findings imply that, in biological systems, both sensory and motor functions adapt together to accomplish sensorimotor goals. Traditionally, in robotics, once sensory systems are initially calibrated, they are usually never recalibrated again during a motor task: if we want to build a robotic device that can mimic human behaviour then we need to consider this notion of sensorimotor adaptation and the fact that sensory systems are not entirely fixed. This means that our interpretation of sensory data needs to be adapted at the same time as our motor commands in adapting to a new environment.

2. HYPOTHESIS

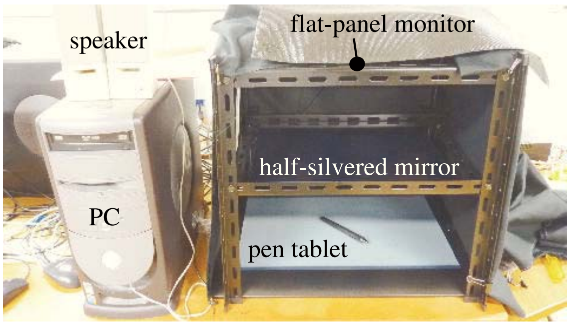
It has already shown that somatosensory perception changes in association with motor learning in reaching movements. Here we focus on visual perception: humans utilize visual information during reaching movements and thus visual perception might be also affected by motor learning.

In this paper, we investigate whether the motor learning has an influence on visual size perception by comparing perceptual judgments obtained before and after a motor learning task that involved reaching movements. Our hypothesis here is that, after a motor learning task that involves precise manipulation or movement, visual objects appear larger than before in the area of the visual workspace used in the task.

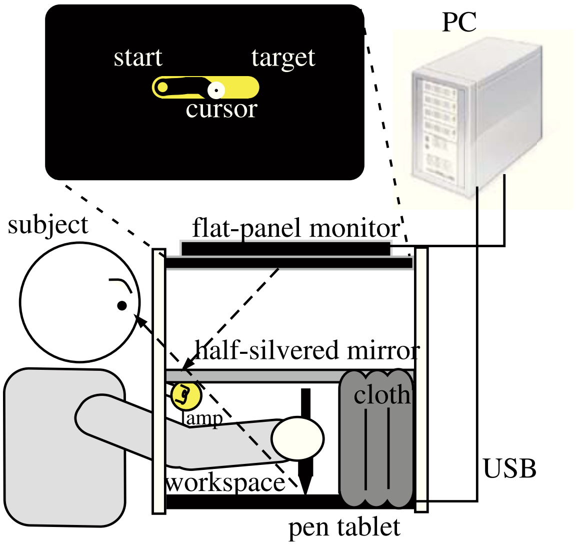
To evaluate this hypothesis, we designed a task of tracing a straight line by using arm movement. The line tracing task, a kind of reaching movement, requires precise control orthogonal to the direction of the line (to stay within the boundary of the line to be traced), but does not require equally precise control in the direction of movement. We expect that in visual perceptual testing, the orthogonal direction will gradually look larger over the course of the line tracing task, but the normal direction should show no changes in visual size perception. As a result, after the repetition of line tracing movements, the line will look thicker than it was before this line tracing task was performed. Therefore, the perception of line thickness, placed in the same location as the traced line, is tested before and after the line tracing task.

3. EXPERIMENTAL SETUP

To realize the line tracing task, we constructed an experimental setup as shown in Fig. 1(a). It consists



(a) photo



(b) Overview during experiment.
Fig. 1 Experimental apparatus.

of a pen-tablet system (detectable area: 487.7mm × 304.8mm: spatial resolution: ±0.25mm, time resolution: max 200 Hz), a flat-panel monitor (size: 442.8mm × 249.0mm, resolution: 1600 × 900 pixels), a half-silvered mirror and a frame in which they were placed.

Figure 1(b) illustrates how this experimental setup works. Subjects grasp the pen of the pen-tablet system while performing reaching movements. The pen-tablet system is used to detect the position of the hand, or more precisely, the pen tip. A flat-panel monitor is mounted above the workspace, and a half-silvered mirror is placed in the middle between the monitor and the pen-tablet. The position of the cursor and the line that is to be traced are displayed on the flat monitor and then projected onto the half mirror: We can display the cursor at the same position as the pen tip, because we know the positional relationship between the flat panel monitor and the pen tip on the tablet when the subjects observe the workspace from a fixed location over the half mirror, as shown in Fig. 1(b). Using this projection, we can display the line that is to be traced, and the start and target position of the reaching movements in the workspace.

If the workspace is illuminated by turning on a lamp below the mirror, the subjects can directly see the hand as well as the pen and its tip. On the other hand, when the workspace is darkened by covering it with a thick black cloth, subjects cannot see the hand or pen any longer. In this latter case, subjects know the position of the pen tip only from the cursor information projected on the half mirror, and from associated somatosensory inflow.

The pen tip position is sampled in real-time every 10ms. The computer graphics on the flat monitor are updated every 25ms using the programing language Tcl/tk. The positional data such as the pen tip and cursor are shared in the same memory area with these two processes. Art-linux has been installed as the operating system.

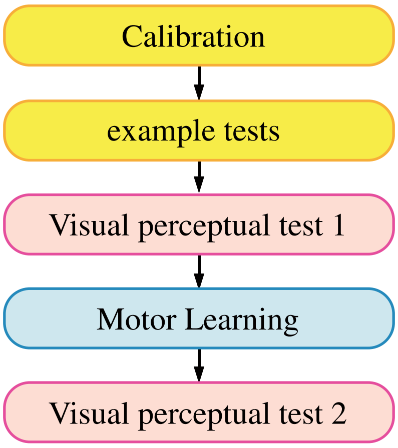


Fig. 2 Procedure of experiment.

4. EXPERIMENT

4.1 Procedure

Figure 2 shows the procedure that we have used here. This procedure consists of a motor learning task involving 150 line tracing movements, and two visual perceptual tests for estimating the perceptual thickness of the line placed at the same position as the traced line.

At the beginning of the testing sequence, a calibration task is performed to relate positions displayed on the half-silvered mirror with the pen tip positions seen through it. 12 points are projected one by one on the half-silvered mirror. Subjects are asked to bring the pen tip to this point. Then, the cursor coordinates on the monitor and the pen tip coordinates from the pen-tablet are obtained at the same time. The bilinear approximation relates the spatial relationship between the two coordinate systems: the coefficients are estimated by the least mean squares method.

At the end of the calibration procedure, subjects are asked to choose a comfortable position on the tablet along the body midline by using the pen. This position is set used a anchor point for the following motor learning and visual perceptual tests.

Next, in order for subjects to familiarize themselves with these tasks, some example tests are performed. These include approximately ten trials for motor learning task, and twenty judgements from the visual perceptual test. The results of the visual perceptual tests are utilized

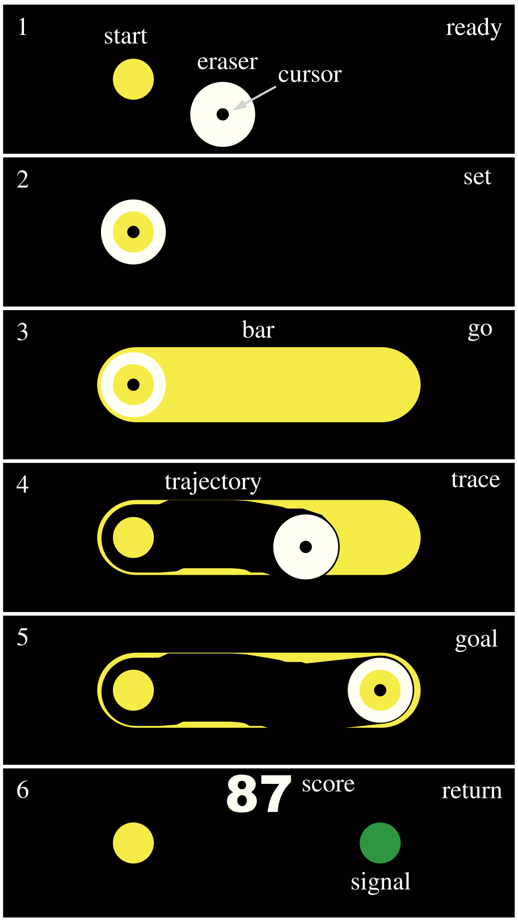


Fig. 3 Motor learning by a line trace task.

to set parameters for the real visual perceptual tests.

4.2 Motor learning

Subjects are told to grasp the pen with their right hand. Next, they are asked to perform the line tracing task.

To clarify the goal of the task, we ask subjects to eliminate the line using an eraser on the half mirror, as shown in Figure 3. The eraser is displayed as a large white circle of 100 pixels (27.7mm) diameter, whose center coincides with that of the cursor, a black circle of 4 pixels (1.1mm) diameter. The position of this cursor changes in conjunction with the pen movement: Basically, the cursor is projected at the same position as the pen tip. Accordingly, the subject can manipulate this eraser by moving the hand anywhere they choose. Subjects are asked to complete the erasing movement by a one-shot motion of the pen in the right hand, while keeping their wrist straight and only moving the arm. During this tracing task, the workspace is darkened by covering the sides of the frame with a black cloth. Thus, the subjects cannot watch the hand and arm directly: the cursor is the only cue that helps them determine the position of the hand.

At first, the start position is presented as a yellow circle composed of 50 pixels (13.9mm) (step 1). The subject has to move the cursor into this circle and remain there (step 2). 1s later, a yellow bar, 556 pixels (154mm) in length and 110 pixels (30.5mm) in width, appears accompanied by a short beep (step 3). It should be noted that the midpoint of this bar coincides with the anchor point that was set at the end of the calibration phase. Subjects are required to delete the yellow bar using the eraser, a large white circle, whose trajectory is shown with the background color, black. Thus, the part of yellow bar, where the eraser has passed, disappears (step 4). The target, a yellow circle having the same 50 pixel diameter (13.9mm) as the start position, is present at the opposite side of the bar (step 5). The subject is instructed to move the cursor to this target with a one way movement. When the subject arrives at the target, the cursor has to stay inside the target circle for 1s. Each trial of the tracing task finishes in this way.

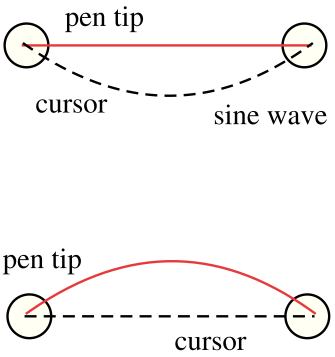


Fig. 4 Positions of pen tip and cursor in motor learning task.

Before the start of the next trial, the entire bar disappears. Subjects are required to bring their hand back to the start position by themselves. During this time, the cursor is not presented. Instead, an evaluation of the latest trial in terms of spatial precision and movement duration are fed back to the subject: the precision score is calculated based on a length ratio, the distance over which the eraser remained inside the yellow bar divided by the distance of the reaching movement. Feedback on movement duration is presented visually and auditorily: The color of the target position turns red, green or blue. If the duration is less than 0.9 s, the target color turns red indicating “move slower” on the next trial. If the duration is greater than 1.1 s, the color turns green, meaning “move faster”. Otherwise, the color turns blue. Simultaneously, the subjects hear different beeps depending on the colors, or more exactly, the movement duration of the last trial. When the pen tip return to within 7.5cm of the start position, the score and target disappear. Next, the eraser with the cursor are again presented, as shown in the top of Fig. 3 and the next trial of the line tracing task starts again from step 1.

To ensure that motor learning occurs, we intentionally displayed the eraser as well as the cursor at a position that is slightly deviated from the pen tip. In fact, the eraser is shown as moving on sine-wave path, as indicated in the top of Fig. 4, when the pen tip actually travels straight. Under these conditions, subjects must move the pen tip on an opposite sine-wave path in order to perfectly erase the yellow bar, as shown in the bottom panel in Fig. 4.

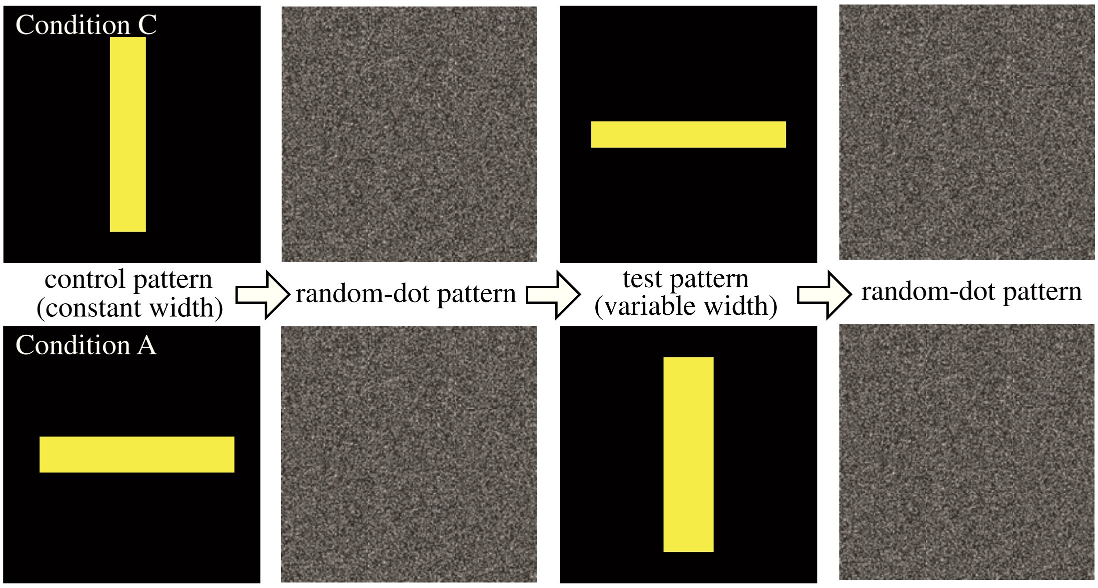


Fig. 5 A method to present the visual perceptual test.

Accordingly, subjects have to learn a new trajectory to get a higher score. The task thus requires motor learning.

4.3 Visual perceptual tests

We hypothesize that learning to follow a precise visual trajectory makes objects look larger in directions where the precise control has been required. According to this hypothesis, lines parallel to the reaching movements should look thicker as a result of motor learning, because precise control is required orthogonal to the direction of the reaching movements required for line tracing.

To examine this prediction, we displayed a yellow bar as a test pattern at the same position as the motor learning, and asked subjects to judge the thickness of the bar. To simplify a task for subjects, we asked them to compare the thickness of this test pattern and a control pattern, and to indicate "which bar is thicker?". A control bar orthogonal to the test pattern was used for this comparison. The reason is that if the control and the test bar were parallel to one other, both might be affected by motor learning in the same manner because their orientations are identical.

Figure 5 illustrates two examples of the visual perceptual tests: the top is a test associated with the horizontal line tracing task, while the bottom is for the vertical line tracing task. At first, the control pattern is displayed on the screen: the midpoint of this bar coincides with the anchor point and the width is constant. The subject can see this bar for 1s. Next, to minimize the effects of visual sensory memory, four random dot patterns are switched one by one every 150ms repeatedly. 2.1 s later, a test pattern appears. The length is the same as the distance of the line tracing task, but the width changes on each perceptual trial. The subject can view this test bar for 1s. Then, the random dot patterns are presented again. The subjects is then required to respond to the question, "Which was thicker, the vertical bar or the horizontal bar?"

Test bars of ten different widths are presented. The range of widths is chosen based on the results of the preliminary test that precedes the start of the experiment. The width of the bar for control is always 65 pixels (18.0mm), while, in the example test, the test bars are 1, 3, 5, 7 and 9 pixels thicker or thinner than that of the control (1 pixel = 0.277mm). These ten widths are tested twice. From this result, we estimate the initial neutral width of the test bar at which the subject judges the control and test patterns to be equal in width. In the real test, bars 1, 3, 5, 7 and 9 pixels thicker or thinner than this initial neutral width are selected as the set of ten test patterns.

4.4 Experiments

26 right-handed subjects ages 20-28 were recruited. Half were tested in the horizontal line tracing task (condition A), and the other half in the vertical task (condition C).

In the motor learning part of the procedure, subjects were asked to perform the line tracing task 150 times. The subjects were asked to get as high score as they could by deleting the yellow bar with a one shot movement of the appropriate speed. We gradually shifted the cursor position over the first 20 trials: on the first trial, the cursor position was almost the same as the pen tip, but by the 20th trial it was completely deviated, by 20 pixels (5.5mm) towards the subject (condition A) or by 20 pixels (5.5mm) to the right (condition c) at the mid point of the trace line. This means that the deviations were the same from the 21th to the 150th trial.

In the visual perceptual tests, ten sets of the 10 test patterns are presented to the subjects before and after motor learning: in total 100 judgments were required from each subjects. A test pattern is randomly selected from within each set. The order of the presented horizontal and vertical bars are different in two conditions: The top figures in Fig. 5 illustrate the order in the condition A: a vertical control bar, random dots, a horizontal test bar and random dots. In the bottom figure, the order for condition C is as

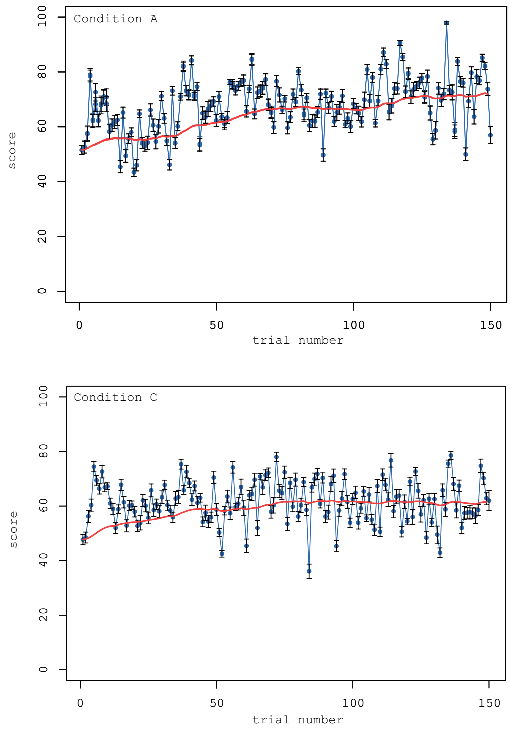


Fig. 6 Score of the line trace task in motor learning.

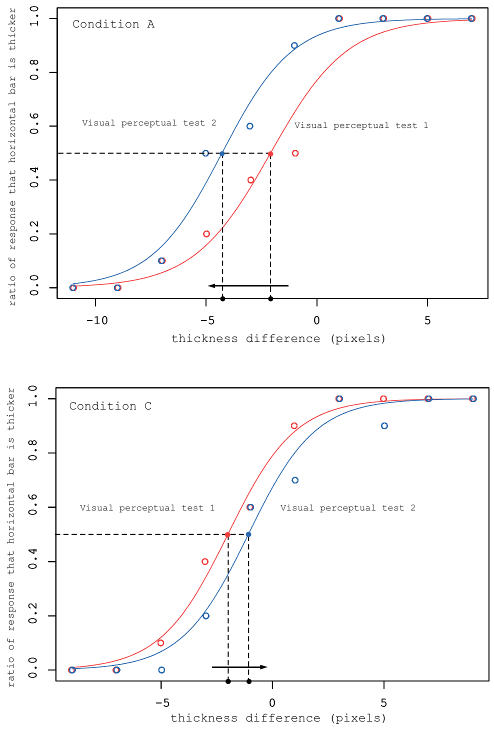


Fig. 7 Psychometric function to detect the perceptual thickness.

follows: a horizontal control bar, random dots, a vertical test bar and random dots. In short, the control pattern is presented first and the test pattern last.

This test was approved by the ethics committee on medical research in Gifu university graduate school of medicine (No. 24-156). All the subjects signed an informed consent form before this test.

5. RESULTS

5.1 Motor learning

In the motor learning phase of the experiment, almost all subjects made an effort to increase their scores. Changes of the mean score over the course of learning in this task are shown in Fig 6. The top figure is the result from condition A and the bottom is from condition C. The blue dots denote the average score on each trial, the black lines with bars denote the standard errors.

The blue lines in both conditions show a tendency to increase, but there is considerable noise. Accordingly a digital filter, a first-order low-pass filter with a 30 trial time constant), was applied. The results are shown as red lines which increase with the trial number, implying that the subjects are learning to trace the line precisely.

5.2 Visual perceptual test

The visual perceptual testing involved 10 tests for each of the 10 different widths. At each width we computed the proportion of cases in which the horizontal bar was judged to be thicker than the vertical bar. These results are plotted in Fig. 7 for a representative subject in each condition: the top is the result from condition A and the bottom is from condition C. The horizontal axis of this graph represents the actual thickness difference on the monitor based on the vertical bar, (horizontal bar width) - (vertical bar width). The vertical axis denotes the proportion of responses in which the horizontal bar was judged to be thicker. Red circles denote the calculation results for the visual perceptual test 1 (before learning), while the blue ones show the result for visual perceptual test 2 (after learning).

The thickness differences shown in these figures indicate the extent to which the horizontal bars are judged to be thicker than the vertical bars. Thus, it is reasonable that the graphs are monotonically increasing functions: the larger the actual difference, the higher the proportion of cases in which the horizontal bar is judged to be thicker. However, we can also observe a difference between visual perceptual test 1 and 2 in the pattern of responses.

In order to evaluate this difference, we estimated the width of the horizontal bar at which the subject judged it was identical to that of the vertical bar. To obtain an estimate of this value, the plotted points were fitted with a binomial function called a psychometric function, based on the least mean square method. The thickness difference associated with the 0.5 ratio, as shown in Fig. 7, is the value for which subjects judged that the horizontal bar was thicker on half of the presentations, implying that the horizontal and vertical bars appeared equal in thickness.

This 0.5 ratio point involves a leftward shift for the subject in the top figure of Fig. 7. This means that a thinner horizontal bar is judged to have same thickness as the constant vertical bar after motor learning. In other words, the horizontal bar appears thicker to this subject than before. This result matches our expectations as outlined in

Table 1 The changes of 0.5 ratio point (pixels).

	Condition A (n=13)												
Visual Test 1	-1.50	-2.09	-4.99	2.09	-3.39	-1.17	-2.09	-2.78	1.64	-1.74	-4.53	-1.48	-4.23
Visual Test 2	-2.55	-4.28	-7.11	3.58	-2.80	-0.58	-2.15	-6.71	-0.30	-1.22	-5.77	-3.65	-4.03
shift direction	-	-	-	+	+	+	-	-	-	+	-	-	+

	Condition C (n=13)												
Visual Test 1	-1.62	-1.76	-0.03	-0.43	0.86	-2.75	2.07	0.00	0.70	-2.21	0.65	-1.60	-2.00
Visual Test 2	-1.44	-0.38	-0.12	0.72	3.60	1.32	3.12	0.43	0.29	-1.06	1.00	-1.43	-1.08
shift direction	+	+	-	+	+	+	+	+	-	+	+	+	+

the previous section. For the subject in the bottom figure of Fig. 7, we can observe a positive perceptual change, which is also consistent with our expectations for the vertical line tracing task.

5.3 Statistic analysis

The 0.5 ratio points were calculated for 13 subjects in each condition. The results are shown in Table 1. It was seen that the 0.5 ratio point shifted in a negative direction for 8 of 13 subjects in condition A, and in a positive direction for 11 of 13 subjects in condition C. The averages for each visual perceptual test in each condition are plotted along with their standard error bars in Fig. 8. This graph suggests that the direction of visual perceptual change for line thickness is opposite in the two conditions: Horizontal line tracing leads subjects to judge the horizontal bar wider, whereas vertical line tracing makes them judge the vertical bar wider. A 2-way ANOVA with a repeated measure (before versus after perceptual testing), assessed differences between the mean values of the four experimental conditions, condition A-visual perceptual test 1 (A1), condition A-visual perceptual test 2 (A2), condition C-visual perceptual test 1 (C1) and condition C-visual perceptual test 2 (C2). A significant statistical interaction was obtained ($F(1, 24) = 11.62, p = 0.0023 < 0.05$), implying that the visual perceptual function differs for the two directions in the line tracing task. Bonferroni-corrected post-hoc tests revealed a difference in the mean values between the group A2 and group C2 ($^{**}p < 0.002$), as well as for the group A1 and group C2 ($^{*}p < 0.01$) while that between the group A1 and group C1 ($p > 0.30$) is not. This interaction is consistent with the hypothesis that human sensory, in this case, visual sensitivity, is enhanced, in behavioural tests, in a manner that corresponds to the directional precision requirements of motor learning. More investigation is needed to clarify the neural pathways by which motor learning might affect visual function and perceptual adaptation.

6. CONCLUDING REMARKS

We hypothesized that motor learning involved in a precise visuomotor task would alter visual size perception. We designed a experimental procedure to assess perceptual change. As a precise manipulation/control task, a line tracing procedure that involved arm reaching movements was selected. We expected that the repetition of the line tracing task would increase the perception of line thickness in directions where there was less tolerance for error (orthogonal to the movement path).

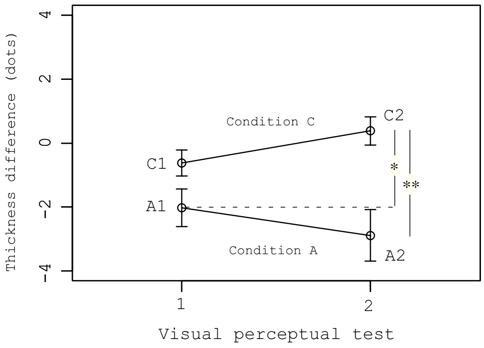


Fig. 8 Change of perceptual thickness.

In order to test these predictions, subjects were tested in the different tracing directions. From the results, we can conclude that the perception of visual line thickness for horizontally presented bars after a horizontal line tracing task differs from that of vertically presented bars after a vertical line tracing task.

However, we have to confirm this effect certainly comes from learning as opposed to simply repeating the tracing tasks. In addition, we have to examine the effect of the order in the presentation of test and control patterns.

REFERENCES

[1] E. K. Cressman and D. Y. Henriques, “Sensory recalibration of hand position following visuomotor adaptation,” *Journal of neurophysiology*, vol. 102, no. 6, pp. 3505–3518, 2009.

[2] N. Malfait, D. Y. Henriques, and P. L. Gribble, “Shape distortion produced by isolated mismatch between vision and proprioception,” *Journal of neurophysiology*, vol. 99, no. 1, pp. 231–243, 2008.

[3] D. J. Ostry, M. Darainy, A. A. Mattar, J. Wong, and P. L. Gribble, “Somatosensory plasticity and motor learning,” *The Journal of Neuroscience*, vol. 30, no. 15, pp. 5384–5393, 2010.

[4] L. E. Brown, E. T. Wilson, M. A. Goodale, and P. L. Gribble, “Motor force field learning influences visual processing of target motion,” *The Journal of Neuroscience*, vol. 27, no. 37, pp. 9975–9983, 2007.

[5] J. K. Witt and T. E. Dorsch, “Kicking to bigger uprights: Field goal kicking performance influences perceived size,” *Perception*, vol. 38, no. 9, pp. 1328–1340, 2009.