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Preference suppression caused by misattribution of task-irrelevant subliminal motion

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It is well known that subjects tend to misattribute task-irrelevant signals, incorporating them into the information on which a decision is made. Such misattribution has been reported to originate only from a social or a cognitive stage of information processing. However, we provide the initial evidence that misattribution also originates at a lower, visuomotor stage. This type of misattribution occurs only when subjects do not notice a visuomotor conflict. Misattribution at a social or a cognitive stage facilitates decision-making if the misattributed information is consistent with the decision and impedes decision-making if the information is in conflict with the decision. However, misattribution originating at a visuomotor stage only impedes decision-making, suggesting a fundamental difference between the mechanisms for the two types of misattribution. Furthermore, misattribution effects that originate in a visuomotor interaction stage also affect subjective preference ratings, suggesting that the misattribution exerts an influence on global brain processing.

Keywords: decision-making; preference; misattribution; visuomotor conflict; consciousness

1. INTRODUCTION

We make thousands of decisions each day. The ability to examine available information and choose the best alternative from out of many is critical to our everyday lives. Yet when we make decisions, our choices are often determined by information that is irrelevant to the decision at hand. Irrelevant emotion-related stimuli [1,2] or cognitive experiences [3,4] that precede a given task can be misattributed to task-relevant signals, thus influencing decision-making [5,6]. It has been found that in many cases misattribution is most likely to occur when subjects are not consciously aware of irrelevant experiences. Thus, misattribution is thought to be the result of the implicit influence of high-level cognitive experiences on decision-making. In the present study, we tested whether misattribution also occurs at a visuomotor interaction stage, and whether misattribution at this lower, more basic level of information processing shares elements in common with misattribution originating in higher social or cognitive stages.

2. MATERIAL AND METHODS

(a) *Subjects*

One hundred and ten subjects (49 males and 61 females) attending Boston University participated in the study. Study design and protocols were approved by the Boston University Office of Research Compliance. All subjects gave written informed consent and had normal or corrected-to-normal vision. Each subject was randomly assigned to one of six experiments (described below).

(b) *Apparatus*

For all experiments, visual stimuli were presented on a LCD display (Viewsonic, VA2226w) with 60 Hz refresh rate using Psychtoolbox v. 3 (http://psychtoolbox.org) on Mac OSX. The experiments were conducted in a dark room, where the only light came from the display.

(c) *Experiment 1*

Twenty subjects participated in experiment 1. The subjects sat in front of the display and performed a preferential decision task (figure 1*a*). Throughout the task, the subjects were asked to fixate their eyes at a white bull's eye point (1° diameter) presented at the centre of the display. At the beginning of each trial, the subjects grasped a joystick (Logitech, Attack 3) with their dominant hand in front of the median line of their body and kept it at a neutral position.

Each trial consisted of two stages: binary decision and rating stages (figure 1*a*). In the binary decision stage, the subjects were presented with two faces simultaneously, one presented on the left and the other on the right of the central fixation point. The subjects were then asked to report a preferred face by moving the joystick leftward or rightward using their dominant hand. After a face presentation, an inclination of the joystick either leftward or rightward by 10° or more was regarded as a response in the binary decision stage. If the response did not occur within 4 s of the face presentation, the trial was terminated. Only 0.7 ± 0.23 trials (mean ± s.e.m.) were discarded owing to terminations for each subject.

Eight hundred face pictures (400 males and 400 females, of a variety of races and ages) collected from several databases [7–12] were used in the binary decision stage. These face stimuli consisted of a face and usually included other body parts such as hair, neck and shoulders, as well as a background scene (each stimulus was 4° square). In each trial, two faces were chosen from the same gender. The order of presentations and positions of face stimuli were randomized across subjects. Each subject was exposed to each face exactly once.

In addition to two face stimuli presented on the left and the right of the central fixation point, task-irrelevant random dot motion was presented on a black background ($59.8 \times 37.4°$ square) in the binary decision stage. The size

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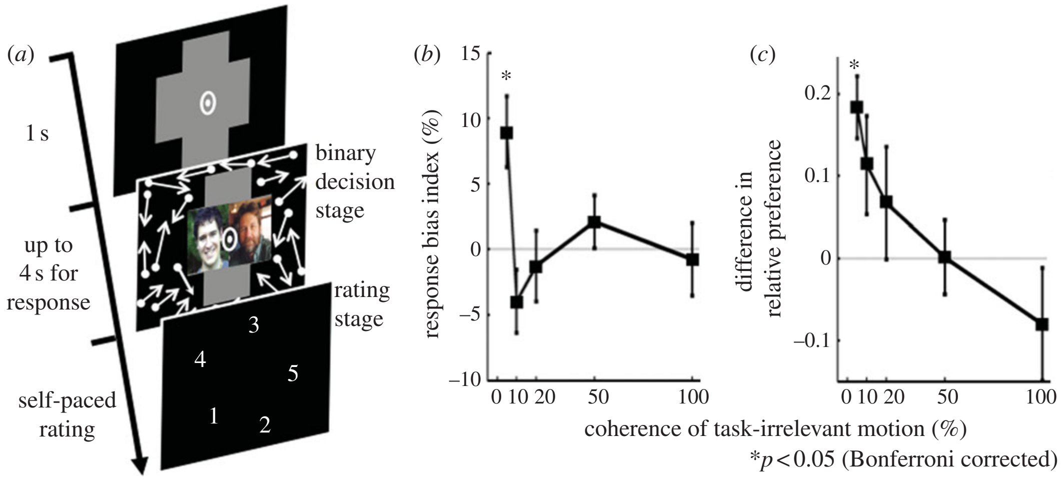

Figure 1. Methods and results of experiment 1. (*a*) Preferential decision and rating. In the binary decision stage of each trial, subjects were asked to report a preferred face (left or right) by moving a joystick either leftward or rightward. In the rating stage of each trial, the subjects were asked to report a relative preference for the chosen face on a five-point scale. (*b*) Response bias indices in the binary decision stage defined as $100 \times$ (number of congruent response trials − number of incongruent response trials)/(number of congruent response trials + number of incongruent response trials). Error bars represent s.e.m. (*c*) Difference in relative preferences between the two response types (congruent, incongruent).

of each white dot was 0.3° square, and dot density was 0.14 dots per ° square. The random dot motion consisted of a mixture of randomly moving dots and a percentage of dots that moved in a uniform direction and speed between frames (frame duration = 16.7 ms). The motion coherence level was varied in a random order from trial to trial in six steps (0, 5, 10, 20, 50 and 100%). The direction of coherently moving dots (motion direction) was also varied in two steps (leftward or rightward). For example, at the 5 per cent coherence level, 5 per cent of the dots moved to predetermined directions from one frame to the next, and then a different set of dots moved in those directions in the next frame transition [13].

Based on subjects' responses in the binary decision stage, individual trials were classified into one of two response types: a congruent response trial or an incongruent response trial. In the congruent response trial, the position (left or right) of the chosen face was consistent with the task-irrelevant coherent motion direction (leftward or rightward). In the incongruent response trial, these two were opposite. We calculated the response bias index, defined as (number of congruent response trials − number of incongruent response trials)/(number of congruent response trials + number of incongruent response trials) × 100, to quantify the effect of task-irrelevant motion on the binary preference decision.

In the rating stage, the subjects were asked to rate a magnitude of the difference between preferences of two faces presented in the binary decision stage ('How much do you prefer the chosen face relative to the other?'). Ratings were given on a five-point scale using the joystick (relative preference; one for the smallest difference, five for the largest difference). Ratings were entered by clicking a cursor on the corresponding digit among a group of equiangularly positioned digits ('1', '2', '3', '4', '5'). The locations of the five digits were randomly shuffled for each trial. This randomly changing configuration ensured that ratings would not be influenced by the location of the chosen face, the direction of the joystick response or the direction of the task-irrelevant motion in the binary decision stage.

After each response in both binary decision and rating stages, the subjects were asked to put the joystick back to the neutral position. During a 1 s inter-trial interval, a grey cross shape (8° in length in both the horizontal and vertical axes) with the bull's eye fixation point was presented at the centre of the display.

Before the onset of the experiment, the subjects were afforded a brief practice session with face stimuli that would not be used in the main experiment. Each subject completed 400 trials of the task in the main experiment (for less than 40 min). After every 50 trials, the subjects were allowed a brief rest period.

(d) *Experiment 2*

Twenty new subjects participated in experiment 2. The procedure was identical to that of experiment 1 except for the rule of joystick response in the binary decision stage. To choose a left (right) face, the subjects were asked to push (pull) the joystick forward (back). The correspondences between the positions of the faces (left or right) and the joystick responses (pushing forward or pulling back) were randomly flipped across the subjects.

(e) *Experiment 3*

Twenty new subjects participated in experiment 3. The stimuli in the binary decision stage were identical to those used in experiment 1. Subjects were asked to press a button on the joystick when they decided on a preferred face. The preferred face was not reported at this stage. In the rating stage, two letters ('L' and 'R') and five digits ('1', '2', '3', '4' and '5') were presented in 10 combinations in a random order equiangularly around the centre of the display (see electronic supplementary material, figure S1*a*). The subjects were asked to report a preferred face and a relative preference by indicating one of the combinations. For example, a subject reported L3 if the preferred face was presented on the left side and the relative preference was 3.

(f) *Experiment 4*

Twenty new subjects participated in experiment 4. The procedure was identical to that of experiment 1 except that an additional coherent motion direction was used as a control. Half of the subjects were presented with upward coherent motion on one-third of trials, while the other half were presented with downward coherent motion. Based on responses in the binary decision stage, individual trials were classified into one of three types: a congruent response trial, an incongruent response trial and a baseline trial in which the direction of task-irrelevant coherent motion and the directions of the joystick movements were orthogonal.

(g) *Experiment 5*

Ten new subjects participated in experiment 5. The procedure was identical to that of experiment 1 except that there was no face presentation and no rating stage in this experiment. In each trial, either leftward or rightward coherent motion was presented on a black background for 1.5 s. After the motion offset, two targets ('Left' and 'Right') were presented below and above the centre of the display. The subjects were asked to report a perceived motion direction by clicking one of the two targets using a mouse-driven pointer. The motion direction, coherence level and positions of the targets were randomly determined for each trial. Each subject underwent a brief practice session and completed 250 trials of the main task (less than 30 min in total). After every 50 trials, the subjects were allowed a brief rest period.

(h) *Experiment 6*

Twenty new subjects participated in experiment 6, which consisted of two tasks: facial preference decision task and motion direction discrimination task. The procedure of the facial preference decision task was identical to that of experiment 1. The procedure of the motion discrimination task was identical to that of experiment 5.

3. RESULTS AND DISCUSSION

(a) *Experiment 1*

In the first experiment, we addressed the question of whether misattribution can originate at a visuomotor stage rather than at a higher social or a cognitive stage. For this purpose, we specifically examined whether task-irrelevant motion can influence decision-making in the context of a facial preference task (see §2 for details).

The response bias indices calculated from subjects' responses in the binary decision stage were significantly different among the five coherence levels (5, 10, 20, 50, 100%; one-way ANOVA with repeated measures, $p = 0.0034$; figure 1*b*). Post hoc *t*-test revealed that the response bias index was significantly larger than zero at the 5 per cent coherence level ($p = 0.018$, Bonferroni corrected), but not at higher coherence levels ($p > 0.5730$). These results indicate that responses were biased towards the direction of task-irrelevant motion only when 5 per cent motion was presented. Response times from the onset of the stimulus presentation to the joystick response were not significantly different between the two response types (see electronic supplementary material, figure S2*a*), ruling out the possibility of a trade-off between response type and response time. Overall, these results are in accord with the hypothesis that a task-irrelevant motion direction presented in the background was misattributed as task-relevant information for preferential decision-making. As indicated in §1, previous studies have concentrated on misattribution that originates in cognitive stages, including those that process emotion [1,2], mood [4] and past choice [3]. However, the results of the present experiment suggest that misattribution can also originate in a visuomotor interaction stage.

Does 5 per cent task-irrelevant coherent motion exert an influence only on subjects' motor responses or on their subjective preference of faces as well? To address this question, we examined whether relative preferences for chosen faces reported in the rating stage are also biased.

We applied two-way ANOVA with repeated measures for the relative preferences, and found a significant interaction between response type and coherence level ($p = 0.0210$), but no significant effect of response type ($p = 0.0614$) and coherence level ($p = 0.7224$). In accord with the response bias found in the binary decision stage, post hoc *t*-test showed the relative preference was significantly higher in the congruent response trials than in the incongruent response trials, again *only when* coherence level was 5 per cent ($p = 0.005$, Bonferroni corrected). Once again, this effect was not found at higher coherence levels ($p > 0.3705$; figure 1*c*; see electronic supplementary material, figure S2*b* for the relative preferences before subtraction). This result indicates that 5 per cent task-irrelevant visual motion biases both decisions and subjective preferences for faces and suggests that misattribution related to visuomotor interactions exerts influences on cognitive processing (i.e. subjective preference).

(b) *Experiments 2 and 3*

The results of experiment 1 suggest that some interaction between the directions of coherent motion and motor response lead to misattribution, but this does not by itself implicate a visuomotor stage as the site of the misattribution. If the misattribution observed in experiment 1 occurs at a higher cognitive stage of processing, we might expect the task-irrelevant motion to influence decision-making irrespective of the particular motor responses employed. If, however, the misattribution does originate in a visuomotor interaction stage, rather than in a cognitive stage, the misattribution should only occur when combinations of visual motion and motor response directions are in direct conflict.

In experiment 2, subjects were asked to select preferred faces by pushing a joystick forward or pulling it backward, instead of moving it leftward or rightward. As in experiment 1, background motion direction was either leftward or rightward. All other procedures were identical to those of experiment 1.

Under the new response rule, we found no significant effect of visual motion as measured on a response bias index (one-way ANOVA with repeated measures, $p = 0.5712$; figure 2*a*). Likewise, two-way ANOVA with repeated measures did not show any significant effects of response type ($p = 0.7760$), coherence level ($p = 0.5464$) or interaction of these two factors ($p = 0.2629$) on relative preferences (figure 2*b*). This result indicates that the misattribution observed in experiment 1 does not occur when the directions of task-irrelevant coherent motion and joystick responses are orthogonal, and therefore independent.

In experiment 3, subjects were asked to participate in another modified face preference task. In this variation, observers viewed the two faces and then pressed a single button indicating that they had formed a preference for

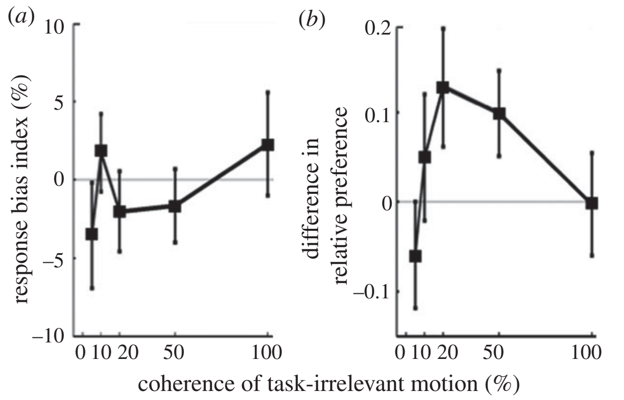

Figure 2. Results of experiment 2. (*a*) Mean response bias indices in the binary decision stage. Error bars represent s.e.m. (*b*) Mean difference in relative preferences between two response types (congruent, incongruent).

one face. Subjects did not report the preferred face at this binary decision stage. Instead, the preferred face was reported together with a relative preference in the rating stage (electronic supplementary material, figure S1*a*; see §2 for details).

Similarly to the results of experiment 2, we found no significant effect of visual motion as measured on a response bias index (one-way ANOVA with repeated measures, $p = 0.8342$; electronic supplementary material, figure S1*b*). Two-way ANOVA with repeated measures also did not show any significant effects of response type ($p = 0.6722$), coherence level ($p = 0.8311$) or interaction of these two factors ($p = 0.9754$) on relative preferences (electronic supplementary material, figure S1*c*).

The results of experiments 2 and 3 suggest that the misattribution observed in experiment 1 occurs with specific combinations of directional signals from visual motion and a motor response, and that the misattribution originates in a visuomotor interaction stage rather than in a cognitive stage.

(c) *Experiment 4*

It has been found that misattribution originating from prior cognitive experiences facilitates decision-making if the direction of the cognitive experiences is consistent (congruent) with relevant information. Likewise, decision-making is impeded if these are in conflict (incongruent) [1,2]. If the misattribution originating at a visuomotor interaction stage occurs under the same processing principles as cognitive misattribution, then it should both facilitate and impede decision-making. In our paradigm, this question was addressed by testing whether 5 per cent task-irrelevant visual motion influences preferences of faces when the directions of motor response and visual motion are congruent (facilitative effect), incongruent (suppressive effect) or both. In experiment 4, procedures were identical to those of experiment 1, except that vertically moving task-irrelevant motion was added as a control direction in the binary decision stage (see §2 for details).

First, as in experiment 1, the response bias index was significantly larger than zero only with 5 per cent task-irrelevant coherent motion (see electronic supplementary material, figure S3*a*). Likewise, the difference between

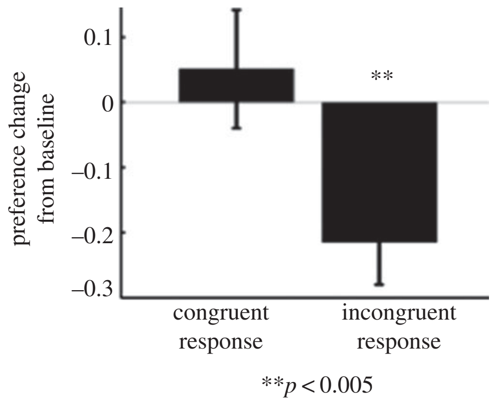

Figure 3. Suppressive effect of 5% visual motion on preference in experiment 4. Error bars represent s.e.m.

relative preferences in the congruent and incongruent response trials was significant only with 5 per cent coherent motion (see electronic supplementary material, figure S3*b*; see figure S3*c* for the relative preferences before subtraction). Thus, the results of experiment 1 were replicated.

More importantly, there was no significant difference between relative preferences in the congruent response and baseline trials at the 5 per cent coherence level (*t*-test, $p = 0.5783$; figure 3). On the other hand, we found that relative preferences in the incongruent response trials were significantly smaller than in the baseline trials ($p = 0.0034$; figure 3). These results indicate that subjective preference decreased when a face was located on a counter side of the task-irrelevant visual motion signal. In other words, 5 per cent task-irrelevant motion has a suppressive effect on subjective preferences for faces, but not a facilitative one. These results are not in accord with the hypothesis that misattribution originating at a visuomotor interaction stage occurs under the same processing principles as cognitive misattribution.

(d) *Experiment 5*

The results of experiments 1 and 4 indicate that only 5 per cent task-irrelevant motion exerts influences on decision preferences. Why would a weak motion signal (and *only* a weak motion signal) exert these effects? We hypothesize that when the task-irrelevant motion is perceivable, the motion signals itself or interactions between the motion and response signals are suppressed, and thus misattribution is avoided. In experiment 5, we tested this hypothesis by measuring the motion direction discrimination performance (see §2 for details).

We found that discrimination performance on the 5 per cent coherent motion was not significantly different from chance (50% accuracy; *t*-test; $p = 0.1585$, no Bonferroni correction), while discrimination performances at higher coherence levels were significantly above chance ($p < 0.001$, Bonferroni corrected; electronic supplementary material, figure S4). This result is in accord with the hypothesis that misattribution occurred only with the 5 per cent coherent motion because this weak coherent motion was not consciously perceived, and that this irrelevant information then biased decision-making. Conversely, when the coherent motion was consciously perceivable, the visuomotor system was able to suppress this information and prevent decision biases.

(e) *Experiment 6*

The result of experiment 5 showed that 5% coherent motion is consciously unperceivable for subjects, suggesting that the misattribution found in experiment 1 occurred only with subliminal motion stimuli. However, different sets of subjects participated in experiments 1 and 5. Thus, in experiment 6 we used the same group of subjects to conduct both the facial preference decision task and motion direction discrimination task.

As in experiment 4, the results of experiment 1 were replicated (see electronic supplementary material, figure S5*a* for the response bias index, figure S5*b* for the difference between relative preferences in the congruent and incongruent response trials, and figure S5*c* for the relative preferences before subtraction) in the facial preference decision task of experiment 6. As in experiment 5, we found that motion direction discrimination performance on the 5 per cent coherent motion was not significantly different from chance (50% accuracy; *t*-test; $p = 0.3991$, no Bonferroni correction) while discrimination performances at higher coherence levels were significantly above chance ($p < 0.001$, Bonferroni corrected; electronic supplementary material, figure S6).

We also examined a relationship between motion sensitivity and effects of task-irrelevant motion on the preference decision. Based on the criterion as to whether subjects' motion direction discrimination performance on the 5 per cent coherent motion was smaller than 52 per cent or not, individual subjects were classified into one of two groups: a lower motion sensitivity group (10 subjects) and a higher motion sensitivity group (10 subjects). For the lower motion sensitivity group, motion direction discrimination performance was not significantly different from chance (*t*-test, $p = 0.1937$). On the other hand, for the higher motion sensitivity group discrimination performance was significantly higher than chance ($p < 0.0005$). We found that the response bias index at the 5 per cent coherence level (see figure 4*a*) was significantly larger than zero for the lower motion sensitivity group (*t*-test, $p = 0.0004$) while there was no effect of the 5 per cent coherent motion on the response bias index for the higher motion sensitivity group ($p = 0.2525$). There was a significant difference between the two groups ($p = 0.0314$). In accord with the response bias index, the relative preference at the 5 per cent coherence level (figure 4*b*) was significantly higher in the congruent response trials than in the incongruent response trials for the lower motion sensitivity group ($p < 0.0001$), while no significant change in the relative preference was found for the higher motion sensitivity group ($p = 0.1339$). There was a marginally significant difference between the two groups ($p = 0.0870$). These results further support the hypothesis that the subliminal motion stimulus leads to the misattribution.

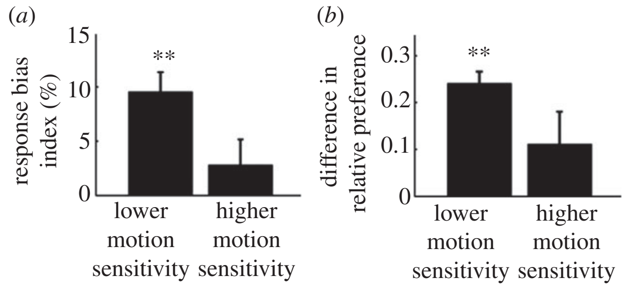

Figure 4. Different effects of 5% coherent motion for the lower motion sensitivity group and the higher motion sensitivity group in experiment 6. (*a*) Mean response bias indices at the 5% coherence level. (*b*) Mean difference in relative preferences between the two response types (congruent, incongruent) at the 5% coherence level. Error bars represent s.e.m. $^{**}p < 0.001$.

(f) *Discussion*

We found that task-irrelevant coherent motion direction signals are misattributed to the information that is relevant to motor responses and subjective ratings of facial preferences. Under our specific task setting, such misattributions occur only when task-irrelevant motion is subthreshold and incongruent with the direction of responses.

Is there any possibility that task-irrelevant visual motion induced eye movements, which are known to influence observers' decisions [14,15], in experiments 1, 4 and 6? It has been shown that stronger background motion induces larger eye movements [16,17]. Given that the effect of task-irrelevant motion was observed only at a low 5 per cent coherence level, and not at higher coherence levels (figure 1*b*,*c*), it is unlikely that eye movements are the main cause of the observed effect. In addition, the results of experiments 2 and 3 showed no effect if the response rule was changed (see figure 2; electronic supplementary material, figure S1). Since the visual presentation during the binary decision stage in experiments 2 and 3 was identical to that of experiment 1, it is likely that the effects found in experiments 1, 4 and 6 depend mainly on response rules, rather than eye movements.

We obtained the robust effects of task-irrelevant motion on the preference decision at the 5 per cent coherence level (see figure 1*b*,*c*; electronic supplementary material, figures S3*a*,*b* and S5*a*,*b*). One may wonder if there was any effect at the higher coherence level, in addition to the effects at the 5 per cent coherence level. For example, the difference in the relative preferences did not drop to zero at the 10 and 20 per cent coherence levels in experiments 1 (see figure 1*c*) and 4 (electronic supplementary material, figure S3*b*). However, these differences in the relative preferences were not significantly larger than zero. In addition, in experiment 6 (see electronic supplementary material, figure S5*b*), the difference in the relative preferences dropped to zero at the 10 and 20 per cent coherence levels. These results indicate that the tendency found in experiments 1 and 4 at the 10 and 20 per cent coherence levels was, if any, very weak or statistically ignorable.

As indicated in §1, it has been reported that emotion-related stimuli [1,2] or cognitive tasks [3,4] modulate evaluation or judgement of subsequently presented items, causing the observer to misattribute the prior cognitive experience as relevant information for the present decision [5,6]. On the other hand, our findings indicate a unique misattribution process, which may be distinguished from well-documented cognitive misattribution processes, in the following aspects. First, the new misattribution originates in a visuomotor interaction stage, rather than the more cognitive/social stages in which conventional misattribution occurs. Second, the new misattribution occurs only in a suppressive way, when a task-irrelevant visual signal is in conflict with a motor response. This suggests a different processing principle from that of conventional misattribution.

Why does the new misattribution occur only in a suppressive way? It is possible that the new misattribution derives from suppression-dominated mechanisms of visuomotor interaction. In our previous study [18], we found that a visuomotor conflict from task-irrelevant motion impeded performance on a perceptual decision task (as in the Simon effect [19]), while no or little performance change occurred when subjects' motor response direction and task-irrelevant motion direction were congruent. This effect was particularly strong when the task-irrelevant motion was weak. Results of the neuroimaging experiment in the previous study suggest that this tendency occurred owing to a failure of inhibition of conflict signals derived from the task-irrelevant motion in the prefrontal cortex [18]. In that study, the subjects reported a colour of coherently moving dots by moving a joystick leftward or rightward, while the dots moved leftward or rightward. The similarity of the procedures between the previous and present studies suggests that the new misattribution found in the present study occurs only in a suppressive way because the visuomotor incongruency, rather than visuomotor congruency, between subjects' joystick movement and task-irrelevant motion strongly affects underlying neural information processing.

In summary, the present findings indicate that our preferences are modulated not only by higher-level cognitive processes, such as prior experiences [20] and cognitive biases [21], but also by a simple visuomotor conflict. This effect is particularly strong when the visual signal causing the conflict is not consciously perceivable, and appears to be governed by principles that make it unique from higher cognitive mechanisms.

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