Implicit motor adaptation driven by intermittent and invariant errors

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Abstract

Our movements and movement outcomes are disturbed by environmental changes, leading to errors. During ongoing environmental changes, people should correct their movement using sensory feedback. However, when the changes are momentary, corrections based on sensory feedback are undesirable. Previous studies have suggested that implicit motor adaptation is takes place, despite the realization that the presented visual feedback should be ignored. Although several studies created experimental situations where participants had to continuously ignore the presented visual feedback, in daily lives, people intermittently encounter opportunities to ignore sensory feedback. In this study, by intermittently presenting visual error clamp feedback, always offset from a target by 16° counterclockwise, regardless of the actual movement in a reaching experiment, we provided intermittent opportunities to ignore the visual feedback. We found that in the trials conducted immediately after presenting the visual error clamp feedback, reaching movements shifted in the direction opposite to the feedback; a hallmark of implicit motor adaptation. Moreover, the magnitude of the shift was significantly correlated with the speed of motor adaptation to gradual changes in the environment. Correcting movement according to continuous environmental changes is essential to maintain a precise movement. Therefore, the results suggest that people, unintentionally, react to momentary environmental changes that should be ignored and the sensitivity to momentary changes is greater in people who adapt quickly to the relevant gradual environmental changes.

Keywords: error-based learning, motor adaptation, implicit learning, sensory prediction error

Declarations

Contribution

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Naoyoshi Matsuda. The first draft of the manuscript was written by Naoyoshi Matsuda and Masaki O. Abe commented on the manuscript versions. All authors read and approved the final manuscript.

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Data availability

The datasets of the current study are available at figshare (https://doi.org/10.6084/m9.figshare.21212843.v1).

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Ethics approval

This study was approved by the Ethics Committee of the Faculty of Education at Hokkaido University (approval number: 21-08).

Introduction

States of the body and environment are not constant; they continue to change. The sensorimotor system needs to adjust movements according to the changes to maintain a precise movement. However, people often encounter situations where they are not required to adjust their movement according to the changes in the body and the environment. For example, if a golf ball is sliced due to wind, where the wind is momentary, people would not consider the wind in the subsequent shot. People must not adjust their movement based on sensory feedback that is strongly affected by accidental or momentary environmental changes.

Recent studies, using the visual error clamp feedback, have suggested that implicit motor adaptation takes place despite the realization that the presented visual feedback should be ignored (Morehead et al. 2017; Kim et al. 2018, 2019, 2022; Tsay et al. 2020, 2021a, b, 2022; Avraham et al. 2021). During the reaching tasks in these studies, a visual feedback cursor follows a fixed trajectory. This trajectory is always deviated from a target by a fixed angle. Such visual feedback is called visual error clamp feedback. The clamp feedback yields sensory prediction error, i.e., the difference between the actual and the predicted sensory feedback from a motor command. Implicit motor adaptation is believed to be driven by sensory prediction error (Shadmehr et al. 2010). Moreover, the error causes the adaptive process regardless of intention or explicit strategy (Mazzoni and Krakauer 2006; Taylor and Ivry 2011; Lee et al. 2018). Therefore, even though participants have full knowledge of the visual error clamp feedback and receive the instruction to ignore the clamp feedback and reach the target directly, the angle of their reaching shifts in the direction opposite to the clamp feedback, a hallmark of implicit motor adaptation, through the course of the experimental task (Morehead et al. 2017). In previous studies, experimenters created situations where participants had to continuously ignore the presented visual feedback, constantly presenting the visual error clamp feedback.

However, in daily life, people rarely encounter opportunities to continually ignore sensory feedback. Rather, they often intermittently experience sensory feedback that should be ignored, similar to the golf example above. Nonetheless, the impact of the intermittent error clamp feedback, when the error clamp feedback is in the minority and the rest of the feedback reflects self-movement, has not been examined. This study investigated the impact of the visual error clamp feedback under such a condition. We expect that the intermittent clamp feedback would drive implicit motor adaptation under such a situation, considering that the continuous presence of the error clamp feedback changed the direction of reaching movement even at an early stage (Morehead et al. 2017).

In addition, this study examined an individual difference in sensitivity to the visual error clamp feedback, i.e., the extent to which the movement angle shifts in the direction opposite to the feedback. Since states of the body and the environment often change gradually, people seem to require to adjust their movement according to the change. Indeed, previous studies showed that when visuomotor perturbation is gradually introduced, humans can adapt to the gradual changes by moderately adjusting their movement

(Baddeley et al. 2003; Izawa and Shadmehr 2011; Herzfeld et al. 2014). We examined the relationship between the speed of adaptation to gradual environmental changes and the sensitivity to the intermittent error clamp feedback. By investigating this relationship, we can discuss whether people who adapt quickly to gradual environmental changes react greatly to momentary environmental changes that should be ignored. To the best of the authors' knowledge, this has not been examined. In addition, from the relationship, we can also infer a similarity between implicit motor adaptations based on sensory prediction errors that should be corrected and those that should not be corrected. Previous studies have investigated implicit motor adaptation by generating either type of sensory prediction error (Krakauer et al. 2019; Kim et al. 2021). However, it is not obvious that the two types of sensory prediction error similarly drive motor adaptation. This study measured the sensitivity to the intermittent error clamp feedback and the speed of motor adaptation to gradual changes in the environment, and examined the relationship between the two factors. In cases where we did not find a positive relationship, implicit motor adaptation may have been driven by the error in a different way manner, depending on whether the error should be corrected or not.

Materials and Method

Participants

Twenty young adults (nine women, 11 men, aged 19–29) and ten young adults (five women, five men, aged 19–27) were recruited for Experiments 1 and 2. All the participants were right-handed and healthy volunteers who had never been diagnosed with developmental or neurological disorders. This experiment was approved by the Ethics Committee of the Faculty of Education at Hokkaido University (approval number: 21-08) and written informed consent was obtained from all the participants.

Reaching Task

Participants held a digitizing pen and performed reaching movements across a digitizing tablet (Intuos Pro, Wacom, Japan). The position of the pen was recorded at 120 Hz. All visual stimuli were displayed on a 25-inch LCD monitor (GigaCrysta, I-O DATA, Japan), 24 cm above the tablet. Direct vision of the hand was occluded by the monitor (Fig. 1a). The experimental task was controlled by the custom written in MATLAB (MathWorks, USA), using Psychtoolbox extensions (Kleiner et al. 2007).

Participants moved from a starting position (red circle; 1 cm diameter) and reached a visual target (green circle; 1 cm diameter) positioned 7 cm away at 150° with their right hand. The position of the hand was indicated by a visual feedback cursor (white circle; 0.3 cm diameter), which was provided until participants' movement amplitude exceeded 7 cm during the reaching movement. They were instructed to make a fast-reaching movement to the target, i.e., "shooting" movement, without stopping at the target. Once the movement amplitude exceeded 7 cm, the feedback cursor turned yellow and froze for 1000 msec at the position. If the movement was not completed within 300 msec, "TOO SLOW" appeared on the monitor and a long "buzzer" sound was played. If the movement happened at the correct speed (duration <

300 msec), yet the cursor missed the target, a short “buzzer” sound was played. The sounds of the too slow trial and the miss trial were distinctly different, making it easy for the participants to distinguish between them. If the movement happened at the correct speed and the cursor hit the target, a “ding” sound was played and a point was given. The total point and the current number of trials were continuously displayed on the monitor. Participants were instructed to obtain as many points as possible throughout the experimental task.

Once the feedback cursor disappeared, participants were required to return their hand position to the starting position. A white ring was displayed on the monitor, centered on the starting position. The radius of the ring was the distance between the hand position and the starting position. Guided by the ring, participants moved their hands back to the starting position. When the radius came within 1 cm, the ring transformed into a white cursor. Once the position of the digitizing pen was maintained within the starting position for 1000 msec, the target reappeared.

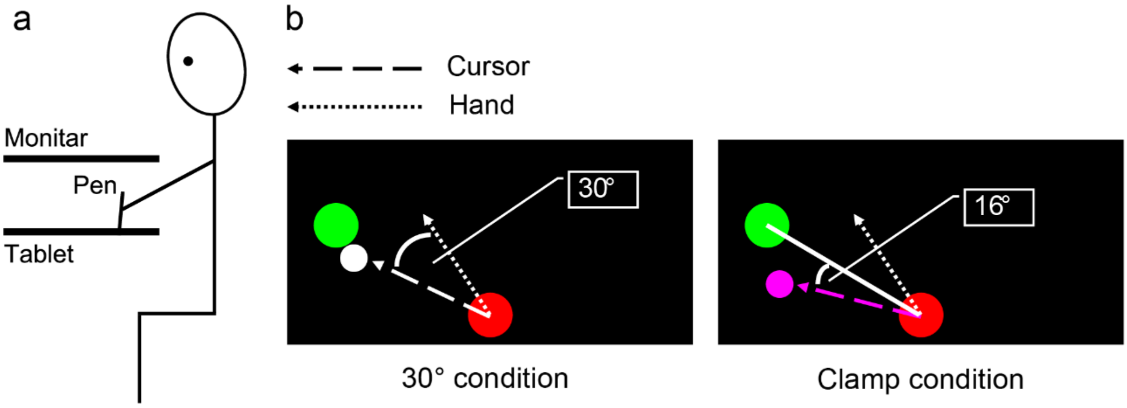

Fig. 1a Scheme of the experimental setup. Participants held a digitizing pen and performed reaching movements across a digitizing tablet while a direct vision of their right hand was occluded by a monitor. **b** Illustration of the two conditions in the maintenance block. The position of the hand was displayed by the visual feedback cursor (a white circle). Green and red circles represent target and starting position, respectively. Under the 30° condition, the cursor rotated 30° counterclockwise from the participants’ actual movement. Under the clamp condition, the cursor always offset from the target by 16°, regardless of the angular position of the hand, although their movement amplitude was reflected in the distance of the cursor from the starting position. The cursor turned magenta when the movement amplitude exceeded 1 cm under the clamp condition.

Procedure

All the participants completed 10 trials with veridical visual feedback (zero-rotation) as the baseline block. Next, they completed adaptation blocks consisting of 180 trials. In the adaptation blocks, the visuomotor perturbation increased by 0.25° counterclockwise per trial until it reached 30° (120 trials; adaptation block

1) and the 30° perturbation lasted for 60 trials (adaptation block 2). Using the gradual introduction of visuomotor rotation, the participants adapted to the environmental changes with less awareness of the perturbation and few explicit strategies (Izawa and Shadmehr 2011; Taylor and Ivry 2013). Since adaptation block 1 alone may not be sufficient for them to adapt to the 30° rotation environment (Herzfeld et al. 2014), they performed adaptation block 2 and reached the asymptote in the adaptation blocks. Following those blocks and a short break (20 sec), they began the maintenance block, consisting of 200 trials. Fig. 2a illustrates the experimental procedures.

Experiment 1

As the primary purpose of Experiment 1, we examined the effect of the intermittent error clamp feedback on the following movement. Participants were divided into two groups: Clamp Group (n = 10, five women) and Control Group (n = 10, four women). In the Control Group, the visual feedback was rotated 30° counterclockwise in all 200 trials within the maintenance block. The Clamp Group received 150 trials with 30° rotation feedback (30° condition) and 50 trials with visual error clamp feedback (clamp condition; Fig. 1b). Under clamp condition, the cursor was always offset from the target by 16°, regardless of the angular position of the hand, although their movement amplitude was reflected in the distance of the cursor from the starting position. The trial order in the Clamp Group was constrained so that three 30° conditions and one clamp condition were presented in cycles of four trials and the clamp condition did not occur twice in a row.

Participants in the Clamp Group were fully briefed on and experienced the visual error clamp feedback before starting the experimental task. Before the maintenance block, the participants were instructed that the visual error clamp feedback would sometimes be presented and they should continue to reach the target irrespective of the feedback. They would not find out whether the visual error clamp feedback would be presented or not until they began the reaching movement. However, the cursor turned magenta when the movement amplitude exceeded 1 cm under the clamp condition. Furthermore, when the movement amplitude exceeded 7 cm, the cursor remained magenta and a “knocking” sound was played. Thus, the participants were able to understand whether visual error clamp feedback had been introduced or not after the reaching movement.

Experiment 2

We tried to replicate the results of Experiment 1. The focus was to investigate the relationship between the speed of motor adaptation to gradual changes in the environment and the sensitivity to the visual error clamp feedback. Thus, Experiment 2 included only the Clamp Group of Experiment 1.

Data analysis

All analyses were performed with MATLAB. We measured the hand angle, defined by the angle between the lines connecting the starting position to the target and the starting position to the hand position at peak velocity. They computed the changes in hand angle from the clamp condition to the subsequent trial in the direction opposite to the visual error clamp feedback (Δ hand angle). The positive value indicated that the hand angle shifted in the direction opposite to the clamp feedback; a hallmark of implicit motor adaptation. Regarding the measure of the speed of motor adaptation to the gradual introduction of visuomotor rotation, we fit a linear function ($y = a \times x$, where y was hand angle at trial x and a was slope) through the time course data in adaptation block 1 and calculated the slope for each participant (Taylor and Ivry 2013). The larger the value of the slope, the faster the implicit motor adaptation to gradual environmental changes.

For statistical analyses, we used the median value of Δ hand angle and the mean of other measurements for each participant. All t-tests and correlation analyses were two-tailed. When the sphericity assumptions for analysis of variance (ANOVA) were not met, Greenhouse-Geisser-corrected values were reported. Bonferroni corrections were used for multiple comparisons following ANOVA. The significance level was set at α = 0.05.

Result

Experiment 1

To confirm whether the hand angle reached the asymptote in the adaptation blocks, the authors divided the blocks into nine mini-blocks of 20 trials each (Figs. 2a and 2b). ANOVA on hand angle with mini-block showed a significant main effect ($F[4.372, 83.063] = 2196.520$, $p < 0.001$, ηp2 = 0.991) and post-hoc tests revealed that the hand angle increased with the increasing perturbation until the seventh mini-block (all $t[19] > 8.212$, $p < 0.001$). Among adaptation block 2 (last three mini-blocks), the hand angle did not increase further (all $t[19] < 0.043$, $p = 1$). The results indicated that motor adaptation reached the asymptote through the adaptation blocks.

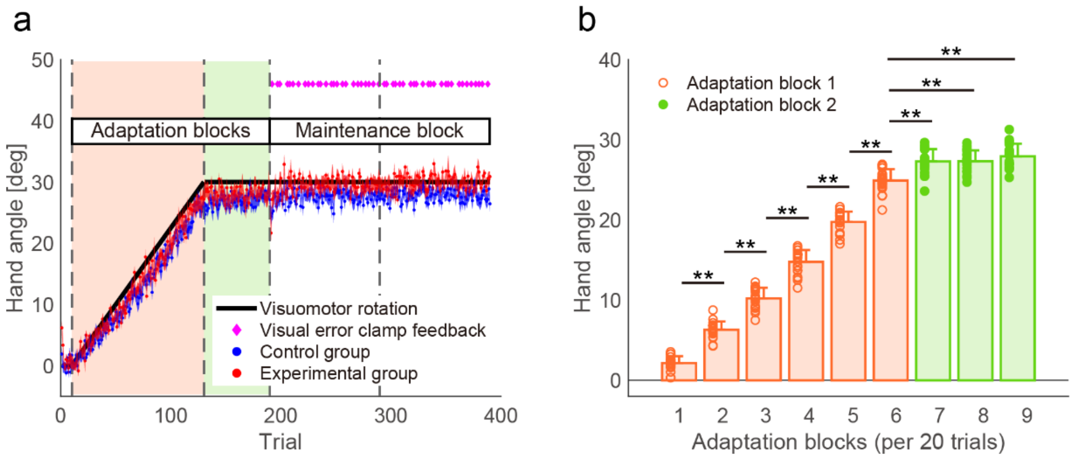

Fig. 2a The time course of mean hand angle in the Control and Clamp Groups. The thick line indicates imposed perturbation. Diamond denotes implementation of clamp condition or the presentation of visual

error clamp feedback, instead of 30° condition in the Clamp Group. The shaded area represents standard errors. **b** Changes in hand angle during adaptation blocks. Data from both groups were shown undiscriminating and the adaptation blocks were divided into nine mini-blocks of 20 trials each. Dots indicate individual means and error bars represent standard errors.

We examined the impact of intermittent clamped visual feedback. ANOVA on hand angle with the measurement point (last 20 trials in adaptation block 2, first and second half in maintenance block) and group (Clamp, Control) was conducted (Fig. 3a). This analysis showed significant effects of both the factors (measurement point: F[1.485, 26.734] = 9.069, $p = 0.002$, ηp2 = 0.335; group: F[0.743, 13.367] = 7.127, $p = 0.016$, ηp2 = 0.284) and significant interaction (F[1.485, 26.734] = 4.097, $p = 0.039$, ηp2 = 0.185). Post-hoc tests revealed that in the Clamp Group, the main effect of the measurement point was significant (F[2, 18] = 24.443, $p < 0.001$, ηp2 = 0.731) and the hand angle increased during the maintenance block (all t[9] > 3.544, $p < 0.019$), while in the Control Group, the hand angle did not significantly change after adaptation block 2 (F[2, 18] = 0.491, $p = 0.620$, ηp2 = 0.052). Furthermore, although the hand angle of both the groups did not significantly differ in adaptation block 2 (t[18] = 1.085, $p = 0.292$), the angle of the Clamp Group was significantly larger than the Control Group (first half: t[18] = 3.263, $p = 0.004$; second half: t[18] = 3.229, $p = 0.005$) in the maintenance block. The results indicate that in the Clamp Group, the motor adaptation reached the asymptote once in adaptation block 2 and was re-driven during the maintenance block.

Next, we focused on the Clamp Group and compared the hand angle among the trials under clamp condition (T), the subsequent trials (T + 1), and the trials that followed (T + 2; Fig. 3b). T + 1 was 30° condition because clamp condition did not occur twice in a row and T + 2 included both the conditions. ANOVA showed a significant main effect (F[2, 18] = 48.846, $p < 0.001$, ηp2 = 0.844) and post-hoc tests revealed that the hand angle on T + 1 was significantly larger than that on T and T + 2 (both t[9] > 8.411, $p < 0.001$). The hand angle on T and T + 1 was not significantly different (t[9] = 0.066, $p = 1$). The results indicated that immediately after the presentation of the visual error clamp feedback, the reaching movements shifted in the direction opposite to the feedback, however, the shifted movements were not sustained.

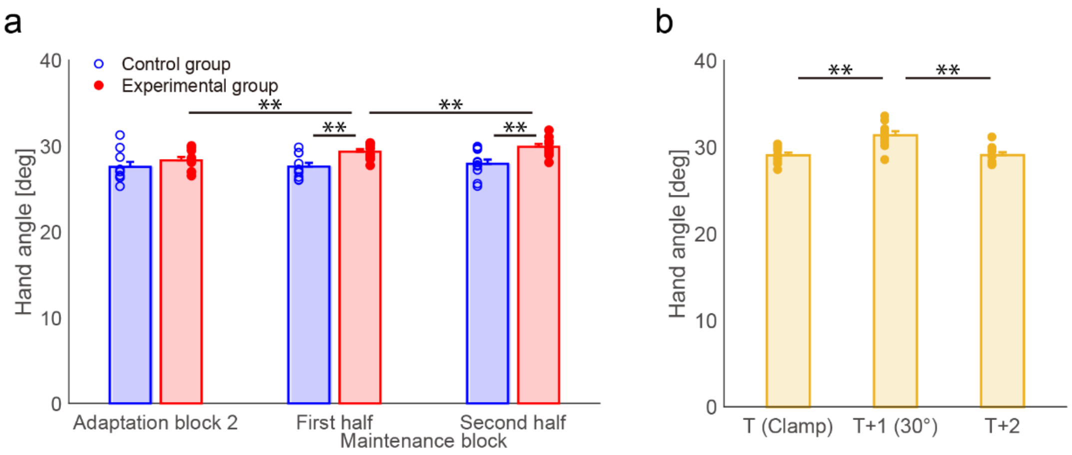

Fig. 3a Changes in hand angle after adaptation block 2 in the Control and Clamp Groups. The maintenance block was divided into the first half and second half of 100 trials each. **b** The impact of visual error clamp feedback on the subsequent movements in the Clamp Group. The next trial (T + 1) of clamp condition (T) was the 30° condition because the clamp condition did not occur twice in a row. The trials that followed (T + 2) included 30° condition and clamp condition. Dots indicate individual means. Error bars represent standard errors. **p* < 0.05, ***p* < 0.01.

Finally, we investigated the relationship between the speed of motor adaptation to gradual changes in the environment and the sensitivity to the visual error clamp feedback in the Clamp Group (Fig. 4). As a measure of the speed of motor adaptation to the gradual introduction of visuomotor rotation, we calculated the slope when fitting a linear function through the time series of hand angles in adaptation block 1. Δ hand angle between clamp condition and the subsequent trial was used as a measure of sensitivity to the visual error clamp feedback. According to Pearson's correlation analysis, Δ hand angle was significantly correlated with the slope (r = 0.717, *p* = 0.020).

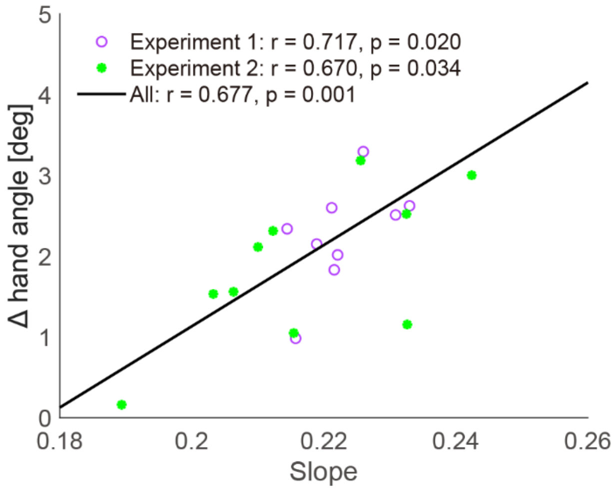

Fig. 4 The Relationship between Δ hand angle and the slope. The slope was calculated by fitting a linear

function through the time series of hand angles in adaptation block 1. Δ hand angle is the change in the hand angle from the clamp condition to the subsequent trial in the direction opposite to visual error clamp feedback. Solid lines indicate a linear regression in the pooled data of Experiment 1 (Clamp Group) and Experiment 2.

Experiment 2

Many analyses yielded similar results as the Clamp Group in Experiment 1 (Fig. 5). The hand angle increased until the seventh mini-block (ANOVA with mini-block in adaptation blocks: F[2.718, 24.465] = 715.866, $p < 0.001$, ηp2 = 0.988; sixth vs seventh: t[9] = 4.062, $p = 0.102$; others: t[9] = 5.712, $p < 0.010$) and reached the asymptote once in adaptation block 2 (all t[9] < 1.605, $p = 1$; Figs. 5a and 5b). Furthermore, ANOVA with measurement point (last 20 trials in adaptation block 2, first half and second half in maintenance block) and post-hoc tests showed that the hand angle re-increased in maintenance block in adaptation block 2 (F[1.297, 11.670] = 14.808, $p < 0.001$, ηp2 = 0.622; adaptation block 2 vs first half in maintenance block: t[9] = 2.849, $p = 0.057$; others: t[9] < 3.816, $p < 0.012$; Fig. 5c). In maintenance block, the hand angle on the subsequent trial of clamp condition (T + 1) was larger than that on T and T + 2 (F[2, 18] = 38.848, $p < 0.001$, ηp2 = 0.812; both t[9] > 5.922, $p < 0.001$, whereas T vs T + 2: t[9] = 1.785, $p = 0.324$; Fig. 5d). Consistent with Experiment 1, the results indicated that intermittent error clamp feedback induced implicit motor adjustment.

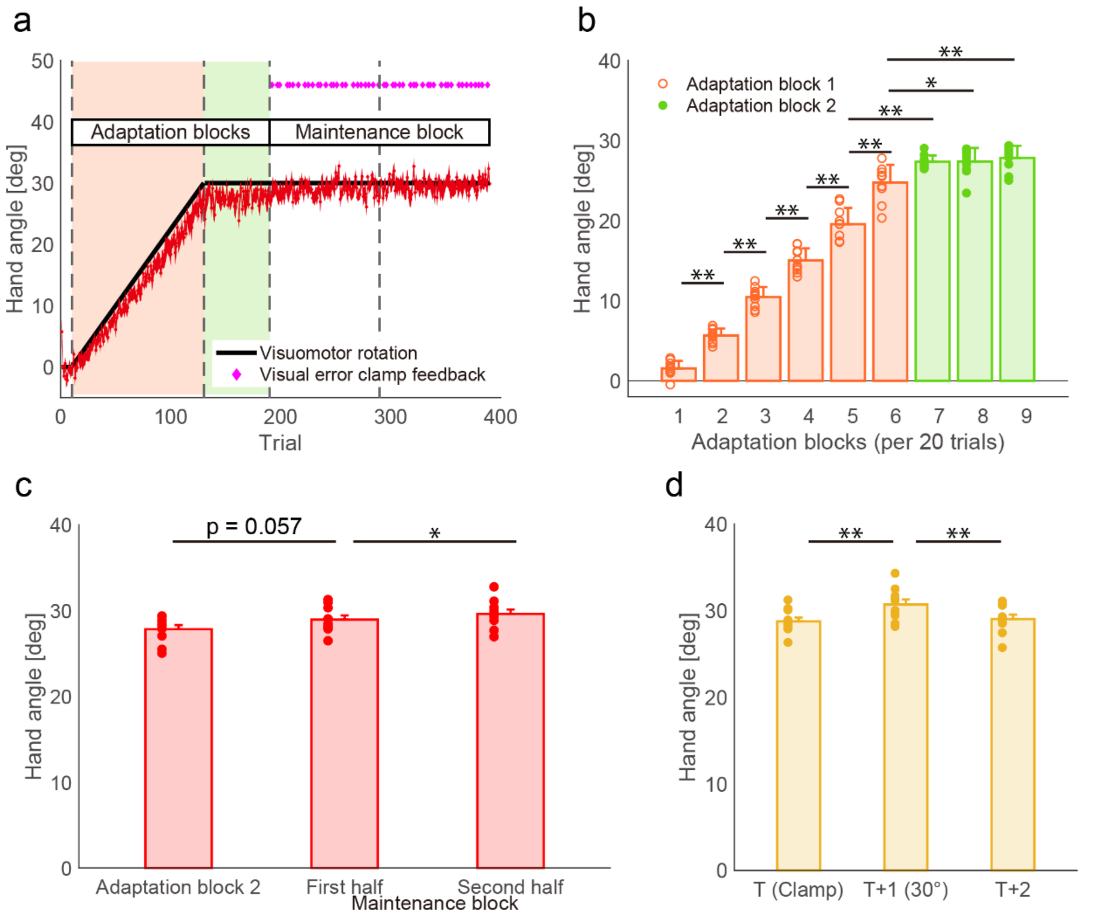

Fig. 5a The time course of mean hand angle in Experiment 2. The thick line indicates the imposed perturbation. Diamond denotes implementation of clamp condition or the presentation of visual error clamp feedback. The shaded area represents standard errors. **b** Changes in the hand angle during adaptation blocks. Adaptation blocks were divided into nine mini-blocks of 20 trials each. **c** Changes in the hand angle after adaptation block 2. The maintenance block was divided into the first half and second half of 100 trials each. **d** The impact of visual error clamp feedback on the subsequent movements in the Clamp Group. The next trial (T + 1) of clamp condition (T) was the 30° condition because the clamp condition did not occur twice in a row. The trials that followed (T + 2) included 30° condition and clamp condition. Dots indicate individual means. Error bars represent standard errors. *$p < 0.05$, **$p < 0.01$.

The primary purpose of Experiment 2 was to examine the relationship between the speed of motor adaptation to gradual changes in the environment and the sensitivity to the intermittent error clamp feedback. Pearson's correlation analysis revealed that Δ hand angle was significantly correlated with the slope (r = 0.670, $p = 0.034$; Fig. 4). Finally, we analyzed the pooled data of Experiment 1 (Clamp Group) and Experiment 2. As a result, Δ hand angle was significantly correlated with the slope (r = 0.677, $p = 0.001$). The results indicated that the faster participants adapted to gradual environmental changes, the more sensitive they were to intermittent error clamp feedback that should be ignored.

Discussion

Recently, visual error clamp feedback has been employed in reaching tasks. Using the clamp feedback, the visual feedback cursor follows a fixed trajectory that always deviates from the target at a fixed angle. Even though the participants had full knowledge of the visual error clamp feedback and tried to ignore it and reach the target directly, the angle of their reaching shifted in the direction opposite to the feedback throughout the task (Morehead et al. 2017). This was because the visual error clamp feedback yielded sensory prediction error, driving implicit motor adaptation.

Several previous studies continuously presented the visual error clamp feedback, indicating an error of the same magnitude and direction, however, the impact of the intermittent error clamp feedback was examined by only a few studies. The current study showed that the shift of the following movement was caused by the intermittent presentation of the visual error clamp feedback when the visual feedback of most trials reflected the actual movement (Figs. 3b and 4d). In line with the results of this study, the continuous presence of the clamp feedback changed the direction of the reaching movement at an early stage (Morehead et al. 2017; Kim et al. 2018, 2019; Tsay et al. 2020, 2021a, b; Avraham et al. 2021). In addition, Tsay et al. (2022) used the visual error clamp feedback that deviated from a target with different magnitudes and directions (clockwise and counterclockwise) in each trial, rather than in the same magnitude and direction as was done in previous studies. The study showed that participants' reaching movement shifted in the direction opposite to the clamp feedback presented in the preceding trial. Kim et al. (2022) observed this phenomenon where they conducted a trial where the visual error clamp feedback was given and that where visual feedback, cursor, was not given. Our results are consistent with previous findings and suggest that implicit motor adaptation is driven by the intermittent occurrence of sensory prediction error even if the error should be ignored.

Furthermore, this study investigated the relationship between the speed of motor adaptation to gradual changes in the environment and the sensitivity to the intermittent error clamp feedback (Fig. 4). A measure of the first factor corresponded to the slope when fitted with a linear function through time series of the hand angles in adaptation block 1. The measure of the second factor corresponded with the changes in the hand angle from the clamp condition to the subsequent trial in the direction opposite to the visual error clamp feedback (Δ hand angle). A significant relationship between the slope and Δ hand angle was observed in both experiments. Therefore, this study suggests that people who adapt quickly to gradual environmental changes react greatly to momentary environmental changes that should be ignored.

Regarding the effect sizes of correlation analysis, $r > 0.5$ generally indicates a large effect size (Cohen 1988). We observed $r > 0.6$ as the result of the correlation analyses. In this study, the slope reflects implicit motor adaptation driven by sensory prediction error that should be corrected, while Δ hand angle reflects implicit motor adaptation driven by sensory prediction error that should not be corrected. Thus, this study suggests a large similarity between the adaptations. Previous studies have investigated implicit motor adaptation by generating sensory prediction errors that should or should not be corrected (Krakauer et al. 2019; Kim et al. 2021). Our data suggest that experiments about implicit motor adaptation would yield similar results, regardless of the types of sensory prediction error.

A limitation of this study is that the experiment results are localized. In the current experiments, visuomotor rotation was increased by a fixed angle (i.e., 0.25° counterclockwise) per trial during adaptation block 1 and the visual error clamp feedback was always offset from the target by a fixed angle (i.e., 16° counterclockwise) during maintenance block. The measures of motor adaptation were calculated based on the hand angle in either block. In other words, this study presented only a similar sensory prediction error for acquiring a measure of motor adaptation. On the other hand, to measure a trial-by-trial motor adaptation, previous reaching studies often presented sensory prediction errors of various magnitudes in both directions (e.g., clockwise and counterclockwise), using visuomotor perturbation or visual error clamp feedback (He et al. 2016; Stark-Inbar et al. 2017; Avraham et al. 2020). In addition, previous studies reported that the rate of the trial-by-trial motor adaptation was affected by the size and direction of the visuomotor perturbation (Wei and Körding 2009; Kasuga et al. 2013; Hutter and Taylor 2018) and the size of the deviation from the target caused by the visual error clamp feedback (Tsay et al. 2022). Therefore, the results of the current study must be replicated in future studies, employing an experimental method that can generate sensory prediction errors of various magnitudes in both directions, for acquiring a measure of trial-by-trial motor adaptation.

Conclusion

The state of the body and the environment continues to change gradually in most cases. According to the changes, people can adjust their movement to maintain precision. However, people often encounter a situation where they should not adjust their movement according to the changes, such as an accidental and momentary change in the environment. This study showed that people, unintentionally, adjust their movement based on the intermittent visual feedback that should be ignored. Besides, we found that people who adapt more quickly to gradual environmental changes react more greatly to momentary environmental changes that should be ignored. Implicit motor adaptation may be driven similarly by sensory prediction error, regardless of whether the error should or should not be corrected.

Declarations

Contribution

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Naoyoshi Matsuda. The first draft of the manuscript was written by Naoyoshi Matsuda and Masaki O. Abe commented on the manuscript versions. All authors read and approved the final manuscript.

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Data availability

The datasets of the current study are available at figshare (https://doi.org/10.6084/m9.figshare.21212843.v1).

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Ethics approval

This study was approved by the Ethics Committee of the Faculty of Education at Hokkaido University (approval number: 21-08).

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