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Original Article

The modulation of motor control by imitating non-biological motions: a study about motor resonance

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Abstract. [Purpose] Sensorimotor experience modulates motor resonance, such as motor interference, which occurs when observing others' movements; however, it is unclear how motor resonance is modulated by intentionally imitating others' movements. This study examined the effects of imitation experience on subsequent motor resonance. [Subjects and Methods] Twenty-seven healthy participants performed horizontal arm movements while observing non-biological, incongruent (vertical) movements of a visual stimulus (triangle object) in pre- and post-test procedures. Thirteen participants in the imitation group imitated vertical movements (non-biological motion) of the triangle object between pre- and post-test procedures and fourteen participants in the non-imitation group observed that. [Results] Variance in the executed movements was measured as an index of motor resonance. Although there was no significant difference in the non-imitation group, there was a significantly smaller variance for post-test compared to pre-test in the imitation group. [Conclusion] Motor resonance was inhibited by intentionally imitating non-biological motions. Imitating movements different from one's own motor property might inhibit subsequent motor resonance. This finding might be applied to selectively using motor resonance as a form of rehabilitation.
Key words: Motor control, Motor resonance, Sensorimotor experience

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INTRODUCTION

There has been much discussion about the effects of observing others' movements on motor control. Previous studies have shown that observing others' movements has an interference effect on executed movements[1, 2)]. For example, variability in executed movements increases when an observer executes horizontal or vertical movements while observing others' incongruent (horizontal or vertical) movements[1)]. This motor interference effect occurs not only when observing human movements, but also when observing non-biological object's movements. This has the property of linear motion with constant velocity, which is distinct from human motor properties[2, 3)]. The effects of observing others' movements, such as the motor interference effect, are interpreted as motor resonance[4)].

Several studies have reported findings on motor resonance such as the synchronization of the postural sway between participants standing face-to-face[5)], and the enhancement of reaction speed on movements by observing others' fast movements[6)]. Motor resonance has various effects on subconscious motor control; therefore, the motor control of patients with movement disorders might be improved by using motor resonance as a form of rehabilitation. However, the visual information of others' movements may also disturb one's own movement performances[7, 8)]. To apply motor resonance in rehabilitation, it is necessary to clarify the requirements of motor resonance.

Some researchers have discussed that motor resonance is based on the mirror neuron system (MNS)[1, 9–12)]. MNS comprises

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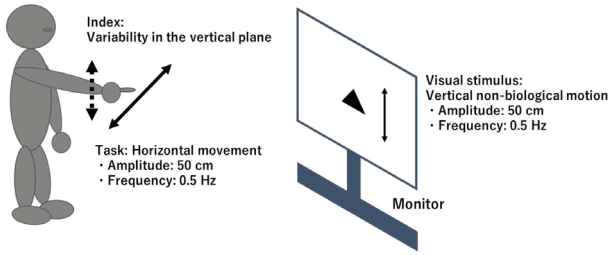

Fig. 1. Experimental set up.

human premotor and parietal cortices that matches observation and execution of actions[13–15]. The areas that comprise MNS are active, not only when actions are executed, but also when the same actions are observed[15–17]. Several studies showed that sensorimotor experience modulates MNS activity[18, 19]. Moreover, Capa et al. showed that providing participants with short-term visuo-motor experience in performing an action increases the subsequent motor interference effect[20]. It seems that motor resonance depends on MNS activity, and sensorimotor experience modulates the degree of motor resonance[20–22].

However, it is unclear what kind of sensorimotor experience modulates motor resonance. Consequently, this study focused on imitation experience because many individuals who require motor learning will often intentionally imitate others' movements. Imitation is primarily based on MNS[23–27]. Imitation experience may affect subsequent motor resonance because both intentional imitation and automatic motor resonance depend on MNS activity. Therefore, examining the effects of imitation based on MNS is key to clarify the requirements of motor resonance. This study examined the effects of imitation experience on subsequent motor resonance by measuring the motor interference effect as an index of motor resonance.

SUBJECTS AND METHODS

Twenty-seven healthy undergraduate students (16 men, 11 women, mean age=19.8 ± 1.6 years) from Kobegakuin University (Kobe, Japan) participated in the study. All participants were randomly assigned to the imitation group (n=13, seven men, six women, mean age=18.5 ± 0.5 years) or the non-imitation group (n=14, nine men, five women, mean age=21.1 ± 1.3 years). Each participant provided written, informed consent. This study was approved by the ethics committee of Kobegakuin University (HEB16-06) and conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki.

The experiment followed Kilner and colleagues' paradigm[1] to measure the motor interference effect. Participants stood 1.3 m from the monitor (Hewlett-Packard, HP ZR2740w, 600 × 340 mm) and performed horizontal movements with their right arm at 0.5 Hz while observing the visual stimulus displayed on the monitor (Fig. 1). For horizontal movements, participants' right shoulder joint was flexed about 90°, and their elbow joint was extended. A horizontal movement of participants' shoulder joint was executed with an amplitude of 50 cm. Variability in movement trajectory in the vertical plane of horizontal movements was measured as an index of the motor interference effect. Participants' fingertip position was recorded via an infrared sensor attached to the right index finger, using a 3D motion capture system (nac Image Technology Inc., MAC3D system) sampling at 120 Hz.

The experimental procedure followed a test-retest protocol. The measurements were conducted in the following order: (1) baseline 1, (2) pre-test, (3) post-test, and (4) baseline 2. Participants performed 13 cycles of horizontal movements in each phase. Participants became familiar with the task by practicing before performing in baseline 1. During practice, the sound of a metronome provided a rhythm at 0.5 Hz and the ruler presented 50 cm (i.e., amplitude); when participants understood the rhythm and amplitude, the practice was ended. The visual or auditory (sound of a metronome) stimuli were controlled by Hot Soup Processor 3.4 (Onion Software) installed on a Windows computer.

During baseline 1, participants performed horizontal movements according to the rhythm (0.5 Hz) provided by the sound of a metronome, without the visual stimulus. In the pre-test, the triangle object (▲), which moves in the vertical direction at 0.5 Hz was displayed as a visual stimulus on the monitor (Fig. 1). The movement amplitude of the triangle object was 50 cm. The motor property of the triangle object was non-biological motion, which has the property of linear motion with constant velocity, which is distinct from human motor properties[3]. Participants performed horizontal movements orthogonal to vertical movements of the triangle object. The post-test was conducted to investigate the change of motor interference effect from pre-test to post-test. Participants performed the same movement task as the pre-test in the post-test. Baseline 2 was conducted to investigate the influence of fatigue[20]. Participants performed the same movement task as baseline 1 in baseline 2.

The experience phase was set between pre-test and post-test procedures. There were 4 trials in the experience phase. For the imitation group, in each trial, participants imitated 13 vertical movements of the triangle object. For the non-imitation group, in each trial, participants observed 13 vertical movements of the triangle object, but did not execute any movements.

Concerning analysis, the first 2 cycles and the last 1 cycle of horizontal movements were removed from the data to minimize any initial asynchrony between observed and executed movements, and to discard potential inattention or muscular

Table 1. Comparison of variance between baselines in the imitation and non-imitation group

	Imitation group (n=12)	Non-imitation group (n=12)
Baseline 1 (mm^2)	95.7 ± 44.8	91.8 ± 97.0
Baseline 2 (mm^2)	122.8 ± 86.5	71.2 ± 67.6

Values are presented as mean ± standard deviation.

Table 2. Comparison of variance between phases in the imitation and non-imitation group

	Imitation group (n=12)	Non-imitation group (n=12)
Mean-baseline (mm^2)	109.3 ± 57.3	81.5 ± 81.6
Pre-test (mm^2)	185.8 ± 103.9*	143.8 ± 103.6‡
Post-test (mm^2)	109.1 ± 51.8†	152.7 ± 139.2§

Values are presented as mean ± standard deviation.
*Significant difference between mean-baseline and pre-test in the imitation group (p=0.018).
†Significant difference between pre-test and post-test in the imitation group (p=0.018).
‡Significant difference between mean-baseline and pre-test in the non-imitation group (p=0.0013).
§Significant difference between mean-baseline and post-test in the non-imitation group (p=0.011).

fatigue effects, respectively[21]. The data of 10 cycles was split into segments of motion[1, 2, 20]. Therefore, there were 20 movement segments per phase: 10 discrete movements from right to left, and 10 discrete movements from left to right. For each segment, variability was quantified by calculating the variance in the vertical plane[1, 2, 20]. For each phase, the mean of the variances was calculated across all 20 segments.

Since this study aimed to understand the effects of experiences on motor resonance in distinct conditions (i.e., imitation or observation), the final analysis only included individuals who demonstrated motor interference effect in the pre-test[21] (defined as variance that was numerically larger for the pre-test compared to baseline 1[20]). To detect differences in baselines between groups, a mixed analysis of variance (ANOVA) was conducted with group (imitation group and non-imitation group) as the between-subjects independent variable, phase (baseline 1 and baseline 2) as the within-subjects independent variable, and variance as the dependent variable. Then, the mean of both baselines constituted the "mean-baseline"[20]. To detect differences in phases between groups, a mixed ANOVA was conducted with group (imitation group and non-imitation group) as the between-subjects independent variable, phase (mean-baseline, pre-test, and post-test) as the within-subjects independent variable, and variance as the dependent variable. The modified Bonferroni method was used for multiple comparisons. The significant level was set at $p<0.05$. All data analyses were conducted using R version 3.3.2 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Two participants (one in each group) who did not show a motor interference effect at pre-test were removed from the data analyses. In addition, data for one participant from the imitation group were removed from analyses because the mean variance was more than 2.5 standard deviations from the grand mean. Therefore, 12 participants (seven men, five women, mean age=18.5 ± 0.5 years) in the imitation group, and 12 participants (seven men, five women, mean age=21.0 ± 1.3 years) in the non-imitation group were included in analyses.

No main effect of group and phase (baseline 1 and baseline 2) or interaction effect was found (all ps>0.05) (Table 1). There was a significant interaction between groups and phases (mean-baseline, pre-test, and post-test) ($F=4.11$, $p=0.023$). Post hoc analysis showed that there was significantly larger variance for the pre-test compared to the mean-baseline ($p=0.018$) and to the post-test ($p=0.018$) in the imitation group, there was significantly larger variance for the pre-test compared to the mean-baseline ($p=0.0013$), and for the post-test compared to the mean-baseline ($p=0.011$) in the non-imitation group (Table 2).

DISCUSSION

There was no significant difference between baseline 1 and baseline 2 between groups. This implies that the conditions

of experience (i.e., imitation or observation) did not induce attentional or muscular fatigue effects in the post-test[19]. In comparison between pre-test and post-test, although there was no significant difference in the non-imitation group, there was significantly smaller variance for the post-test compared to the pre-test in the imitation group. This decreased variance indicates that imitating non-biological motions did not facilitate subsequent motor resonance, but rather induced inhibition of motor resonance.

One interpretation of this finding is the possibility that imitation experience directly inhibited the function of MNS. However, this interpretation is not supported by a previous study that showed that MNS is activated when imitating others' movements[26]. Moreover, some studies showed that observing non-biological motion activates MNS[28, 29]. According to these findings, it is unlikely that imitating non-biological motion directly inhibited MNS activity.

This study suggests a hypothesis that is based on the computational theory of motor control. Some studies have shown that feedback control in motor control might be realized only when sensory feedback is attributed to the self[7, 30] and that sensory self-attribution primarily depends on the forward model[31–33]. The forward model is a system that predicts sensory feedback by using a reference copy of the motor command in the brain[34–36]. Actual sensory feedback is compared with the sensory prediction based on the forward model[34–36]. Consequently, if actual sensory feedback matches the prediction, the sensory feedback will be attributed to the self[31, 37], and be used for motor control (i.e., feedback control)[7]. Conversely, if the sensory feedback does not match the prediction, the sensory feedback would not be used for motor control. The forward model might explain the findings of the present study.

Although the movement direction of the visual stimulus (triangle object) had matched that of participants, the motor property of the triangle object did not match that of participants because the triangle object had a non-biological motion whose velocity and trajectory differed from that of a human[3]. The brain may process not only movement direction information, but also kinesthetic information during action observation[38]. Therefore, the error between the visual feedback (i.e., triangle object's movements) and the sensory prediction of self-movements may have been detected in participants' brains while imitating non-biological motions. As a result of this error detection, participants may no longer have regarded the triangle object as an object used for motor control. It can be presumed that experience of the error detection induced sensory self-other distinction (i.e., distinguishing between participants' movements and triangle object's movements) and inhibited motor resonance at post-test.

This hypothesis suggests that when a patient is imitating a therapist's accuracy movements, if the motor property of the patient is markedly different from that of the therapist due to movement disorders, the patient's brain might induce sensory self-other distinction (i.e., distinguishing between patient's movements and therapist's movements), rather than using the visual information of the therapist's accuracy movements for motor learning. On the other hand, it has been suggested that the error detection between sensory feedback and sensory prediction contributes to motor leaning[39]. Moreover, the results could also be interpreted as follows: imitating movements different from one's own motor properties induces accuracy actions that are not interfered by those movements. The meaning of sensory self-other distinction on imitation should be studied further.

One of the limitations of this study is that it was unclear how many differences there were between participants' motor properties and the triangle object. Even when a healthy individual imitates the movements performed by another healthy individual, it is unlikely that both individuals have the exact same motor properties. A further study about how much sensory self-other distinction on imitation depends on motor properties and what kinds should be conducted. For example, a study that experimentally manipulates the motor property of an object, such as changing its velocity profile to constant velocity (i.e., non-biological velocity), from the motor property of a human, would be of value.

Second, it was unclear whether brain activities other than MNS were involved in inhibition of motor resonance. Using a psychophysics approach, this study hypothesized a mechanism associated with inhibition of motor resonance by revealing changes in motor control. A continuous study of investigating brain activities, such as one that implements a neuroimaging approach, could demonstrate this mechanism. By solving these limitations, the finding of this study might be applied to selectively using motor resonance as a form of rehabilitation, such as modeling accurate movements for patients with movement disorders.

This study examined the effects of imitation experience on subsequent motor resonance by using motor interference effect as an index. The results showed that there was significantly smaller variance after imitating non-biological motion in the imitation group. The findings indicate that imitating movements different from one's own motor properties might inhibit subsequent motor resonance by detecting the error between visual feedback and self-movements based on the forward model in the brain.

Conflict of interest

The authors declare no competing interest.

REFERENCES

1) Kilner JM, Paulignan Y, Blakemore SJ: An interference effect of observed biological movement on action. Curr Biol, 2003, 13: 522–525. [Medline] [CrossRef]

2) Bouquet CA, Gaurier V, Shipley T, et al.: Influence of the perception of biological or non-biological motion on movement execution. J Sports Sci, 2007, 25:

519–530. [Medline] [CrossRef]
3) Kilner J, Hamilton AF, Blakemore SJ: Interference effect of observed human movement on action is due to velocity profile of biological motion. Soc Neurosci, 2007, 2: 158–166. [Medline] [CrossRef]
4) Uithol S, van Rooij I, Bekkering H, et al.: Understanding motor resonance. Soc Neurosci, 2011, 6: 388–397. [Medline] [CrossRef]
5) Okazaki S, Hirotani M, Koike T, et al.: Unintentional interpersonal synchronization represented as a reciprocal visuo-postural feedback system: a multivariate autoregressive modeling approach. PLoS One, 2015, 10: e0137126. [Medline] [CrossRef]
6) Watanabe K: Behavioral speed contagion: automatic modulation of movement timing by observation of body movements. Cognition, 2008, 106: 1514–1524. [Medline] [CrossRef]
7) Asai T: Feedback control of one's own action: self-other sensory attribution in motor control. Conscious Cogn, 2015, 38: 118–129. [Medline] [CrossRef]
8) Nielsen TI: Volition: a new experimental approach. Scand J Psychol, 1963, 4: 225–230. [CrossRef]
9) Asai T, Sugimori E, Tanno Y: The body knows what it should do: automatic motor compensation for illusory heaviness contagion. Front Psychol, 2012, 3: 244. [Medline] [CrossRef]
10) Blakemore SJ, Frith C: The role of motor contagion in the prediction of action. Neuropsychologia, 2005, 43: 260–267. [Medline] [CrossRef]
11) Tia B, Saimpont A, Paizis C, et al.: Does observation of postural imbalance induce a postural reaction? PLoS One, 2011, 6: e17799. [Medline] [CrossRef]
12) Press C, Bird G, Flach R, et al.: Robotic movement elicits automatic imitation. Brain Res Cogn Brain Res, 2005, 25: 632–640. [Medline] [CrossRef]
13) Rizzolatti G: The mirror neuron system and its function in humans. Anat Embryol (Berl), 2005, 210: 419–421. [Medline] [CrossRef]
14) Iacoboni M, Dapretto M: The mirror neuron system and the consequences of its dysfunction. Nat Rev Neurosci, 2006, 7: 942–951. [Medline] [CrossRef]
15) Buccino G, Binkofski F, Fink GR, et al.: Action observation activates premotor and parietal areas in a somatotopic manner: an fMRI study. Eur J Neurosci, 2001, 13: 400–404. [Medline]
16) Rizzolatti G, Fadiga L, Gallese V, et al.: Premotor cortex and the recognition of motor actions. Brain Res Cogn Brain Res, 1996, 3: 131–141. [Medline] [CrossRef]
17) Fadiga L, Fogassi L, Pavesi G, et al.: Motor facilitation during action observation: a magnetic stimulation study. J Neurophysiol, 1995, 73: 2608–2611. [Medline]
18) Catmur C, Walsh V, Heyes C: Sensorimotor learning configures the human mirror system. Curr Biol, 2007, 17: 1527–1531. [Medline] [CrossRef]
19) Calvo-Merino B, Glaser DE, Grèzes J, et al.: Action observation and acquired motor skills: an FMRI study with expert dancers. Cereb Cortex, 2005, 15: 1243–1249. [Medline] [CrossRef]
20) Capa RL, Marshall PJ, Shipley TF, et al.: Does motor interference arise from mirror system activation? The effect of prior visuo-motor practice on automatic imitation. Psychol Res, 2011, 75: 152–157. [Medline] [CrossRef]
21) Roberts JW, Katayama O, Lung T, et al.: The modulation of motor contagion by intrapersonal sensorimotor experience. Neurosci Lett, 2016, 624: 42–46. [Medline] [CrossRef]
22) Press C, Gillmeister H, Heyes C: Sensorimotor experience enhances automatic imitation of robotic action. Proc Biol Sci, 2007, 274: 2509–2514. [Medline] [CrossRef]
23) Wohlschläger A, Bekkering H: Is human imitation based on a mirror-neurone system? Some behavioural evidence. Exp Brain Res, 2002, 143: 335–341. [Medline] [CrossRef]
24) Rizzolatti G, Fogassi L, Gallese V: Neurophysiological mechanisms underlying the understanding and imitation of action. Nat Rev Neurosci, 2001, 2: 661–670. [Medline] [CrossRef]
25) Iacoboni M: Neural mechanisms of imitation. Curr Opin Neurobiol, 2005, 15: 632–637. [Medline] [CrossRef]
26) Iacoboni M, Woods RP, Brass M, et al.: Cortical mechanisms of human imitation. Science, 1999, 286: 2526–2528. [Medline] [CrossRef]
27) Heyes C: Causes and consequences of imitation. Trends Cogn Sci, 2001, 5: 253–261. [Medline] [CrossRef]
28) Gazzola V, Rizzolatti G, Wicker B, et al.: The anthropomorphic brain: the mirror neuron system responds to human and robotic actions. Neuroimage, 2007, 35: 1674–1684. [Medline] [CrossRef]
29) Schubotz RI, von Cramon DY: Sequences of abstract nonbiological stimuli share ventral premotor cortex with action observation and imagery. J Neurosci, 2004, 24: 5467–5474. [Medline] [CrossRef]
30) Toyomura A, Omori T: Auditory feedback control during a sentence-reading task: effect of other's voice. Acoust Sci Technol, 2005, 26: 358–361. [CrossRef]
31) Blakemore SJ, Wolpert D, Frith C: Why can't you tickle yourself? Neuroreport, 2000, 11: R11–R16. [Medline] [CrossRef]
32) David N, Newen A, Vogeley K: The "sense of agency" and its underlying cognitive and neural mechanisms. Conscious Cogn, 2008, 17: 523–534. [Medline] [CrossRef]
33) Haggard P, Chambon V: Sense of agency. Curr Biol, 2012, 22: R390–R392. [Medline] [CrossRef]
34) Wolpert DM, Ghahramani Z, Jordan MI: An internal model for sensorimotor integration. Science, 1995, 269: 1880–1882. [Medline] [CrossRef]
35) Wolpert DM, Kawato M: Multiple paired forward and inverse models for motor control. Neural Netw, 1998, 11: 1317–1329. [Medline] [CrossRef]
36) Wolpert DM, Flanagan JR: Motor prediction. Curr Biol, 2001, 11: R729–R732. [Medline] [CrossRef]
37) Sato A, Yasuda A: Illusion of sense of self-agency: discrepancy between the predicted and actual sensory consequences of actions modulates the sense of self-agency, but not the sense of self-ownership. Cognition, 2005, 94: 241–255. [Medline] [CrossRef]
38) Oouchida Y, Okada T, Nakashima T, et al.: Your hand movements in my somatosensory cortex: a visuo-kinesthetic function in human area 2. Neuroreport, 2004, 15: 2019–2023. [Medline] [CrossRef]
39) Wolpert DM, Miall RC, Kawato M: Internal models in the cerebellum. Trends Cogn Sci, 1998, 2: 338–347. [Medline] [CrossRef]