Behavioral Synchrony: Implicit motor bonding between individuals

Katsumi Watanabe

Waseda University, Tokyo, Japan

Key words: Interpersonal interaction, Motor processes, Social bonding

Running head: Behavioral Synchrony

Word Count: 68 [abstract] / 1519 [text]

Number of Figure: 3

Katsumi Watanabe

Faculty of Science and Engineering

Waseda University

3-4-1 Okubo, Shinjuku, Tokyo 169-0072, Japan

E-mail: katz@waseda.jp

ABSTRACT

We examined motion in persons who attempted to keep their fingers still while pointing to each other and found synchrony in their involuntary micro movements. Short-term follow-the-leader exercises increased the degree of involuntary synchrony; this bi-directional motor bonding was *person-specific* and related to communication skills of the pair. These findings suggest that the microscopic bodily movements reflect identity-specific history of interpersonal interactions and embodied aspects of social connections.

INTRODUCTION

Social coordination occupies a substantial portion of everyday activities (Sebanz, Bekkering & Knoblich, 2006), ranging from spontaneous synchronization to intentional imitations, from body to symbolic languages, and from single pairs to thousands of individuals (e.g., Condon & Sander, 1974; Bargh & Chartrand, 1999; Strogatz, 2003; Néda, Ravasz, Breche, Vicsek & Barabási, 2000; Haken, Kelso & Bunz, 1985; Bernieri, 1988; Schmidt & Richardson, 2008). The degree of interpersonal movement during intentional synchronization has been known to predict social ratings and social bonding (Schmidt & Richardson, 2008; Hove & Risen, 2009; Isabella, Belsky & van Eye, 1989; LaFrance, 1979; van Baaren, Holland, Kawakami & van Knippenberg, 2004; Wiltermuth & Heath, 2009; Miles, Nind & Macrae, 2009), indicating the close relationship between social process and body movement (e.g., Oullier, DeGuzman, Jantzen, Lagarde & Kelso, 2007; Hove, 2008). Interpersonal coordination may spontaneously emerge even when each individual tries to maintain his or her own rhythm or direction of intentional movements (Schmidt & O'Brien, 1997; Kilner, Paulignan & Blackmore, 2003; Richardson, Marsh & Schmidt, 2005). Here we report the simplest case where unintentional microscopic body movements occur even when people try to be still, and it is modulated by person-specific experiences of bi-directional interaction.

Two participants sat face to face and pointed each other with the index-fingers and were told to hold still their fingertips straight in the air. Yet, the finger positions spontaneously deviated back and forth microscopically (as one may experience by trying to hold a laser pointer still on the wall). Each pair initially performed a keep-the-finger-still (pre-adaptation) session. Then, they performed a follow-the-leader exercise session, in which one participant (leader) moved the finger freely and the other (follower) pursued the leader's finger position as accurately as possible. After this adaptation session, they were again asked to hold their finger positions still in a post-adaptation session. Note that the tasks that the pair performed were exactly the same in the pre- and post-adaptation sessions; namely, keeping their finger positions as stationary as possible. We found that the peak cross-correlation between the finger positions of the pair, which manifests the degree of implicit motor bonding, significantly increased after the adaptation.

METHODS

Participants. A total of 233 individuals (age: 18-38 years) participated. All were right-handed, reported no history of mental or developmental disorders, and were naïve to the purpose of the experiments. The procedures were approved by the internal review board and written informed consent was obtained prior to the testing.

Procedures. In the first set of experiments (Experiment 1-2), participants came to the laboratory and were randomly paired with another participant. The pair sat on chairs face to face and asked to point each other with their index fingers (**Fig 1**). The distance was adjusted such that, when they straightened one arm and pointed each other with the index fingers, the distance between the fingertips was within the range of 10 to 20 cm. The pair used the opposite hands for pointing (i.e., mirror-imaged posture). After the finger positions became stable, the experimenter asked them to hold their fingers at the current absolute position and started recording. The measurement duration was 60 seconds for each trial. The arm to be used was alternated for every session to prevent fatigue. In Experiment 1 (51 pairs), each pair initially performed 2 trials (pre-adaptation). Then, they performed an adaptation session where the "leader" moved his/her arm freely and the "follower" tracked the leader's finger position as accurately as possible. The role was assigned randomly but fixed within each pair. A single trial in the adaptation session lasted 60 seconds and was repeated 4 times. After the adaptation session, they performed 2 trials, where they again held their finger positions (post-adaptation). In Experiment 2, two pairs were concurrently examined in the pre- and post-adaptation sessions. However, during the adaptation session, the pairs were switched (52 pairs). The Autism-Spectrum Quotient questionnaire (Baron-Cohen, Hoekstra, Knickmeyer & Wheelwright, 2006; Wakabayashi, Baron-Cohen, Wheelwright, & Tojo, 2006) was filled by the participants of Experiment 1 and 2.

Figure 1. Experimental design. Participants were randomly paired and asked to point each other with the index fingers. The experimenter asked them to hold their fingers at the current absolute position. In Experiment 1, each pair initially performed 2 sessions (pre-adaptation; 60 sec each). Then, they performed 4 adaptation sessions, where the "leader" moved his/her arm freely and the "follower" tracked the leader's finger position as accurately as possible. After the adaptation session, they performed 2 sessions, where they again held their finger positions (post-adaptation). In Experiment 2, two pairs were concurrently examined in the pre- and post-adaptation sessions. But, during the adaptation session, the pairs were switched. In the subsequent set of control experiments, the procedure was identical to that in the previous experiments except that, in the adaptation session, the participant was instructed to hold the finger position still (Experiment 3), to move the finger position independently of the leader's movement (Experiment 4), and to follow the finger position of the leader who was blind-folded (Experiment 5).

In the second set of control experiments with smaller numbers of participants, participants were paired with a partner who was selected randomly out of 4 laboratory members. The partner always played as the leader. The procedure was identical to that in the previous experiments except that, in the adaptation session, the participant was instructed to hold the finger position still (Experiment 3; N=9), to move the finger position independently of the leader's movement (Experiment 4; N=8), and

to follow the finger position of the leader who was blind-folded (Experiment 5; N=10).

Apparatus and Data Acquisition. Infrared reflection markers were attached on the fingernails of the index fingers of participants. The marker positions were recorded at 100 Hz with motion capture systems (Vicon MX®, Colorado, USA in Experiment 1-2; or CL33®, Library, Tokyo, Japan in Experiment 3-5). Although we recorded three-dimensional positions, as most deviations occurred in the horizontal axis, the horizontal position of the finger was registered with the initial position being the origin. A peak of cross-correlation was calculated with the range of temporal lag of ± 5 seconds.

RESULTS

Since the task required participants to keep their finger position still, there was a natural tendency to coming back to the original position, which led to cross-correlations even between participants who were not actually paired. Therefore, we confirmed the peak cross-correlation in the first session of all the experiments was significantly higher for the actual pairs than those made by random shuffling of the obtained data (**Fig. 2**; $P < 0.0001$). This suggested that, even when the participants tried to keep their finger position still as possible, the finger positions tended to implicitly assimilate each other.

Figure 2. The peak cross-correlation between finger positions was significantly higher for the pairs that were that were actually paired than those made by random shuffling ($p < 0.0001$). The peak cross-correlation between finger positions was significantly higher for the actual data than the shuffled data.

The peak cross-correlation between the finger positions of the pair, which manifests the degree of implicit motor bonding, significantly increased after the adaptation (adaptation effect; **Fig. 3a**; Exp 1;

paired t -test, $t(51) = 2.99$, $P < 0.05$). However, no adaptation effect was observed when the adaptation session was performed with another person. That is, when the pre- and post adaptation sessions were performed by pairs of A-B and C-D, but the adaptation session were done by the switched pairs A-D and B-C, no increase in the peak cross-correlation between the pairs of A-B and between C-D occurred (**Fig. 3b**; Exp 2; $t(52) = 1.28$, $P = 0.206$). Thus, the adaptation effect, i.e., the increase of implicit motor bonding, was specific to the pair that played the adaptation session together. We also found that higher communication skills measured in the Autism-Spectrum Quotient (communication skills scores averaged for the pair and the higher communication skills scores of the pair) were significantly related to the magnitude of the person-specific adaptation effect (post adaptation - preadaptation) in Experiment 1 (**Fig. 3c**; $P < 0.05$).

Subsequent control experiments showed no adaptation effect when the follower ignored the leader's movement and hold the finger position still (Exp 3; **Fig. 3d**; $t(8) = 0.586$, $P = 0.574$) and when they moved the finger position independently, instead of following the leader (Exp 4; **Fig. 3e**; $t(7) = 1.178$, $P = 0.277$) during the adaptation session. Thus, active following is critical for the enhancement of implicit motor bonding. Even more intriguingly, no adaptation effect was observed when the leader was blind-folded and therefore could not see the follower's movement and the follower pursued the finger position of the leader (Exp 5; **Fig. 3f**; $t(9) = 0.669$, $P = 0.520$). Thus, the adaptation effect is based on mutual (*bi-directional*) interpersonal feedback loop (Konvalinka, Vuust, Roepstorff & Frith, 2010). All together, the findings indicate that implicit motor bonding genuinely reflects bidirectional interaction and the history of interpersonal interactions between a given pair.

Figure 3. Results from the experiments are shown as the averaged peak cross-correlations with standard errors, separately for pre-adaptation, post-adaptation, and during adaptation. For Experiment 1 and 2, scatter plots are also shown as insets. (a) The peak cross-correlations showed a significant increase only when the followers actively tracked the sighted leaders (Exp 1). (b) Such an adaptation effect was not observed when the person who performed the adaptation session differed from the partner in the test sessions (Exp 2). Further, (c) The communication skill sub-scores in the Autism-Spectrum Quotient (note the higher the score is the poorer communication skills are) showed significant negative correlations with the magnitude of the adaptation effect (i.e., differences between pre- and post-adaptation) for the average scores of each pair and the larger score of the pair. No other sub-score showed significant correlations. In the control experiments, no adaptation effect was observed (d) when the follower kept the finger still (Exp 3) or (e) with moving the finger independently of the leader (Exp 4) or (f) when the leader was blind-folded during the adaptation period (Exp 5).

DISCUSSION

Regarding behavioral and neural processes mediating social bonds, many questions still remain unsolved (Konner, 2004), mainly due to the lack of simple and robust measures of quantifying the formation of social bonding. The present paradigm provides a simple, reliable quantification tool of implicit interpersonal interaction, which is immune to intentions. Possible areas of extensions and applications include, but not limited to, diagnostic and predictive measures of communication skills of each individual as well as a pair (such as parent-child) and examinations of implicit rapport between a given pair (Schmidt & Richardson, 2008; Hove & Risen, 2009; Isabella, Belsky & van Eye, 1989; LaFrance, 1979); van Baaren, Holland, Kawakami & van Knippenberg, 2004; Wiltermuth & Heath, 2009; Miles, Nind & Macrae, 2009). Owing to its simplicity, it is easily applicable to clinical or developmental cases, opening a possibility for a diagnostic tool (e.g., for autism spectrum disorder). Also, detailed analyses will reveal temporal interaction patterns during implicit motor synchrony (Konvalinka, Vuust, Roepstorff & Frith, 2010). Thus, the present finding and procedure will lead to multiple venues of fruitful investigations of social bonds and its relation to bodily movements.

Although underlying neural mechanisms are yet to be investigated, our new paradigm and findings points to a spontaneous self-organizing process that is unique to face-to-face, real-time interaction at mechanical, biophysical, intra-brain, and inter-brain levels (Bressler & Kelso, 2001). One clear future investigation is simultaneous measurement of brain activities (i.e., hypersanning; Montague, P.R. et al., 2002; Tognoli, Lagarde, DeGuzman & Kelso, 2007) for implicit behavioral synchrony. Our behavioral paradigm will be an ideal task because it would minimize motor-related noise in measurements of brain activities, which was done in our previous study (Yun, Watanabe & Shimojo, 2011; Watanabe, 2013).

ACKNOWLEDGMENTS

Thanks are due to Dr. Kohsuke Takahashi, Dr. Masaki O. Abe, and Dr. Shinsuke Shimojo for their contributions to this work. This study was supported by Moonshot Research and Development (20343198), MIRAI program (20349063), CREST (16817876) from Japan Science and Technology Agency, and KAKENHI (17H06344, 17H00753) by Ministry of Education, Culture, Sports, Science and Technology, Japan.

REFERENCES

- Bargh, J.A. & Chartrand, T.L. (1999) The chameleon effect: The perception–behavior link and social interaction. *J. Pers. Soc. Psychol.* **76**, 893–910.
- Baron-Cohen, S., Hoekstra, R.A., Knickmeyer, R., & Wheelwright, S. (2006). The autism-spectrum quotient (AQ): adolescent version. *J. Autism Dev. Disord.* **36**, 343–350.
- Bernieri, F.J. (1988) Coordinated movement and rapport in teacher–student interactions. *J. Nonverb. Behav.* **12**, 120–138.
- Bressler, S.L. & Kelso, J.A.S. (2001). Cortical coordination dynamics and cognition. *Trends Cog. Sci.* **5**, 26–36.
- Condon, W.S. & Sander, L.W. (1974) Neonate movement is synchronized with adult speech: interactional participation and language acquisition. *Science* **183**, 99–101.
- Haken, H., Kelso, J.A., & Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biological Cybernetics*. *Biological Cybernetics* **51**, 347–356.
- Hove, M. J. (2008). Shared circuits, shared time, and interpersonal synchrony. *Behav. Brain Sci.* **31**, 29–30.
- Hove, M.J. & Risen, J.L. (2009). It's all in the timing: Interpersonal synchrony increases affiliation. *Social Cognition* **27**, 949–961.
- Isabella, R.A., Belsky, J., & van Eye, A. (1989). Origins of mother–infant attachment: An examination of interactional synchrony during the infant's first year. *Develop. Psychol.* **25**, 12–21.
- Kilner, J.M., Paulignan, Y. & Blackmore, S.J. (2003). An interference effect of observed biological movement on action. *Curr Biol.* **13**, 522–525.
- Konner, M. (2004). The ties that bind. *Nature* **429**, 705.
- Konvalinka, I., Vuust, P., Roepstorff, A., & Frith, C.D. (2010). Follow you, follow me: continuous mutual prediction and adaptation in joint tapping. *Quart. J. Exp. Psychol.* **63**, 2220–2230.
- LaFrance, M. (1979). Nonverbal synchrony and rapport: Analysis by the cross-lag panel technique. *Soc. Psychol. Quart.* **42**, 66–70.
- Miles, L.K., Nind, L.K., & Macrae, C.N. (2009). The rhythm of rapport: Interpersonal synchrony and social perception. *J. Exp. Soc. Psychol.* **45**, 585–589.
- Montague, P.R. et al. (2002). Hyperscanning: Simultaneous fMRI during linked social interactions. *Neuroimage* **16**, 1159–1164.
- Néda, Z., Ravasz, E., Brechet, Y., Vicsek, T., & Barabási, A.-L. (2000) Self-organizing processes: The sound of many hands clapping. *Nature* **403**, 849.
- Oullier, O., De Guzman, G. C., Jantzen, K. J., Lagarde, J., & Kelso, J. A. S. (2007). Social coordination dynamics: Measuring human bonding. *Social Neuroscience* **3**, 178–192.
- Richardson, M.J., Marsh, K.L., & Schmidt, R.C. (2005). Effects of visual and verbal interaction on unintentional interpersonal coordination. *J. Exp. Psychol. Hum. Percept. Perform.* **31**, 62–79.

- Schmidt, R.C. & O'Brien, B. (1997). Evaluating the dynamics of unintended interpersonal coordination. *Ecological Psychol.* **9**, 189–206.
- Schmidt, R.C. & Richardson, M.J. (2008). Dynamics of interpersonal coordination. In A. Fuchs & V. K. Jirsa (Eds.), *Coordination: Neural, behavioral and social dynamics* (pp. 281–308). Berlin, Germany: Springer-Verlag.
- Sebanz, N., Bekkering, H., & Knoblich, G. (2006) Joint action: Bodies and minds moving together. *Trend. Cognit. Sci.* **10**, 70–76.
- Strogatz, S.H. (2003). *Sync: The Emerging Science of Spontaneous Order* (Hyperion Press, New York).
- Tognoli, E., Lagarde J., DeGuzman, G.C., & Kelso, J.A.S. (2007). The phi complex as a neuromarker of human social coordination. *Proc. Natl. Acad. Sci. U.S.A.* **104**, 8190–8195.
- van Baaren, R.B., Holland, R.W., Kawakami, K., & van Knippenberg, A. (2004). Mimicry and prosocial behavior. *Psychological Science* **15**, 71–74.
- Wakabayashi, A., Baron-Cohen, S., Wheelwright, S., Tojo, Y. (2006). The autism-spectrum quotient (AQ) in Japan: a cross-cultural comparison. *J. Autism Dev. Disord.* **36**, 263–270.
- Wiltermuth, S.S., & Heath, C. Synchrony and cooperation. (2009). *Psychological Science* **20**, 1–5.
- Yun, K., Watanabe, K., & Shimojo, S. (2012). Interpersonal body and neural synchronization as a marker of implicit social interaction. *Scientific Reports*, 2:595.
- Watanabe, K. (2013). Teaching as a dynamic phenomenon with interpersonal interactions. *Mind, Brain and Education*, 7 (2), 91-100.