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BRIEF REPORT

Rocking to the Beat: Effects of Music and Partner's Movements on Spontaneous Interpersonal Coordination

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People move to music and coordinate their movements with others spontaneously. Does music enhance spontaneous coordination? We compared the influence of visual information (seeing or not seeing another person) and auditory information (hearing movement or music or hearing no sound) on spontaneous coordination. Pairs of participants were seated side by side in rocking chairs, told a cover story, and asked to rock at a comfortable rate. Both seeing and hearing the other person rock elicited spontaneous coordination, and effects of hearing amplified those of seeing. Coupling with the music was weaker than with the partner, and the music competed with the partner's influence, reducing coordination. Music did, however, function as a kind of social glue: participants who synchronized more with the music felt more connected.

Keywords: interpersonal coordination, music, synchronization, coupling

Music can move us physically. Listeners often move spontaneously (Clayton, 2007; Keller & Rieger, 2009), synchronizing their movements with music (Bispham, 2006; Toiviainen, Luck, & Thompson, 2009). People also spontaneously coordinate movements with each other (Issartel, Marin, & Cadopi, 2007; Miles, Griffiths, Richardson, & Macrae, 2010; Schmidt & O'Brien, 1997; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2008; Zivotofsky & Hausdorff, 2007). The universality of work songs, marching songs, and dancing suggests that music may be used deliberately to enhance coordination (Gioia, 2006; Reed, 1998; Wiltermuth & Heath, 2009). Does music also enhance spontaneous coordination with another person?

Spontaneous coordination has been studied in tasks in which two people sit side by side, swinging handheld pendulums, oscillating their fingers, or rocking in rocking chairs (for a review, see Schmidt & Richardson, 2008). Even when not told to, participants synchronize intermittently, as a result of seeing the other person's movements. Their coupling appears to be an automatic by-product of self-organizing, dynamical perceptuomotor processes (Kelso, 1995; Kulger & Turvey, 1987; Large, 2000; Richardson, Marsh, & Schmidt, 2005). If so, then hearing the other person move should also elicit coupling (Schmidt & Richardson, 2008).The one previous attempt to assess this prediction proved inconclusive (Schmidt & McGregor, 1997). In other studies, effects of hearing other people's movements were confounded with also seeing them (Néda, Ravasz, Brechet, Vicsek, & Barabási, 2000).

We used a rocking task to compare the spontaneous coupling elicited by music and by another person's movement. For clarity, we will refer to *synchronization* with music, *coordination* with a person, and *coupling* with either. We expected that seeing or hearing the other person rocking would elicit spontaneous coordination of rocking and that seeing and hearing together would have the strongest effect.

We compared coupling with music and with another person. Different dynamics are involved in the two cases. Music influences movement *unidirectionally*, that is, the listener makes all of the changes (see Repp & Keller, 2008). Unidirectional synchronization has been studied by researchers' asking participants to move rhythmically, usually to clicks, tones, or music (Large, Fink & Kelso, 2002; Repp, 2005; Styns, van Noorden, Moelants, & Leman, 2007). Coordination with another person, in contrast, is usually *bidirectional* (Konvalinka, Vuust, Roepstorff, & Frith, 2010). Each person influences the other, and the process evolves over time. We expected the unidirectional influence of the music to be both more abrupt and more noticeable than the bidirectional attraction of the partner. Whether the two attractors would complement or compete with each other and which would exert the stronger influence was less clear.

Method

Undergraduate participants (N = 48; 52% men and 48% women; mean age = 19.0 years, SD = 1.3) were seated 0.5-m apart in two identical rocking chairs, both facing a screen 1 m away. They were told that the purpose of the experiment was to measure how

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rocking would affect their perceptions of pictures. They were asked to rock at a comfortable pace and given no instructions about rocking with the other person or the music.

The experiment had a 2 × 3 (Visual × Auditory) within-subjects design. Three auditory conditions (no sound, rocking sound, music) were each presented twice in counterbalanced order for a total of six trials. In the no-sound condition, participants rocked on a thick rug. In the rocking-sound condition, participants rocked on a thin sheet of sandpaper placed under the rockers of the chair on top of the rug. In the music condition, participants rocked only on the rug while hearing a recorded live performance by George Dalaras of a Greek song, "Natane to '21" [If It Were Only (18)21] (Kougioumtzis & Dalaras, 1970), with a strong, steady beat of 64 beats per minute. Our judgment that this provided a comfortable tempo for rocking was confirmed by its similarity to participants' spontaneous rocking tempo ($M = 69.98$ beats per minute, $SD = 10.29$).

Participants started rocking one at a time. As they rocked, a landscape scene was projected onto a screen in front of them for 30 s. When the image disappeared, they turned their heads to look either at their partner's chair (vision condition) or in the opposite direction (no-vision condition) for 70 s in each direction. Both visual conditions occurred on each trial in counterbalanced order. At the end of each trial, participants stopped rocking and provided ratings of the picture. At the end of the experiment, participants rated whether their rocking pace matched, changed because of the other person, or changed because of the music, and whether they felt strongly connected to their partner (from 1 = *strongly disagree* to 5 = *strongly agree*).

We recorded the motion of the rocking chairs at 60 Hz using a magnetic sensor attached to the headrest of each chair (Polhemus Fastrak, Polhemus Corp., Colchester, VT) and 6-D Research System software (Skill Technologies, Phoenix, AZ). The data were linearly detrended and low-pass filtered. In order to observe how coupling evolved over time, we divided the 70-s duration of each trial into three equal, nonoverlapping 23.3-s segments. Coordination between participants was measured by cross-correlating (r_{xcor}) the position of the chairs during each segment and taking the absolute value of the largest cross-correlation, thus treating in-phase (0°) and anti-phase (180°) movements as equivalent. Rocking without visual or auditory information about a partner's movement provided a baseline measure against which the coordination for each dyad was compared to determine whether it was above chance.

We measured synchronization with the musical pulse by cross correlating the movement of each chair with a sine wave representing the musical pulse, located using the BeatRoot tracking system (Dixon, 2007). To provide a baseline for chance synchronization with the music, we cross-correlated the music sine wave with each participant's rocking when he or she had no visual or auditory information.

Coupling was analyzed with linear mixed-effects models (LMM) because they allowed us to assess change across segments without assuming that the observations for successive segments within each trial were independent as a general linear model (analysis of variance) would require (Kliegl, Rolfs, Laubrock, & Engbert, 2009; Quené & van den Bergh, 2004). Coordination was assessed with a LMM that included vision condition (two levels), auditory condition (three levels), and segments (three levels). Synchrony with music was assessed with a LMM that compared three conditions: vision, no vision, and the estimate of synchronization due to chance. A third LMM compared the average of the two data points provided by each dyad for synchrony (unidirectional coupling) with the one measure of coordination (bidirectional coupling). A fourth LMM compared synchrony with music in the no-vision music condition with coordination in the no-vision rocking-sound condition and in the vision no-sound condition. We used restricted maximum likelihood estimation to derive means for each model. Significant effects were followed by pairwise comparisons with model-derived means and error terms (West, 2009). A Fisher's r-to-z transformation was applied to all cross-correlations, but for ease of interpretation, we show untransformed values. Estimates of effect size are not provided because methods for calculating and interpreting them are not yet standardized for LMM.

Results and Discussion

Interpersonal Coordination

Figure 1 shows mean coordination between partners in the vision and no-vision conditions for the three segments of each trial. Coordination was higher when participants could see each other's movements (vision condition) than when they could not (no-vision condition), $F(1, 391) = 79.40$, $p < .001$. There was no effect of segment, $F(2, 391) = 1.39$, $p = .25$, but there was an interaction between segment and vision condition, $F(2, 391) = 5.85$, $p < .01$. Spontaneous coordination improved across the trial when there was visual information, $F(2, 391) = 5.86$, $p < .01$, and decreased, but not significantly, when there was not, $F(2, 391) = 1.38$, $p = .25$, replicating the findings of Richardson, Marsh, Isenhower, Goodman, and Schmidt (2007). Further, our results demonstrate that coordination evolved rapidly (within the first 23 s of the trial) and continued to strengthen over time.

Figure 2 shows mean coordination in the three auditory conditions, separately for each vision condition. Overall, coordination was affected by auditory information, $F(2, 391) = 13.24$, $p < .001$. Coordination was significantly higher in the rocking-sound

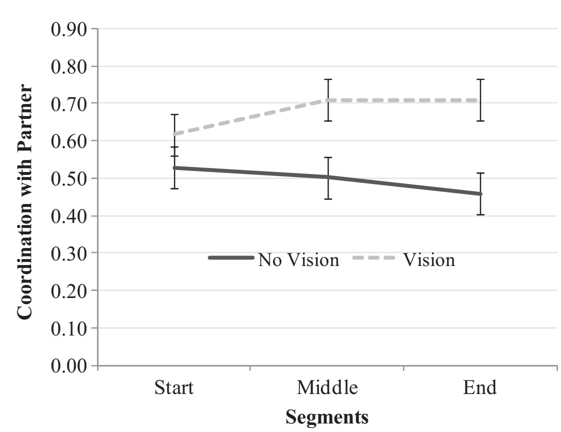

Figure 1. Coordination between partners as a function of three segments and visual information condition. Error bars indicate ± 1 standard error of the mean estimated by the model.

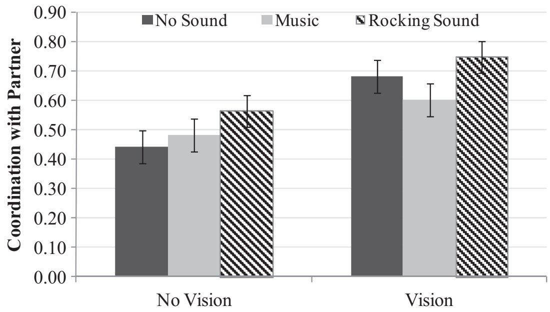

Figure 2. Coordination between partners as a function of auditory condition and vision condition. Error bars indicate ± 1 standard error of the mean estimated by the model.

condition than in the no-sound condition, $t = 3.76$, $p < .05$. The coordination elicited by both people hearing the same music, on the other hand, was not different from no sound, $t = 1.14$, $p = .25$. The effect of rocking sounds supports the view that spontaneous coordination is elicited by information about movement and is not limited to the visual modality (Schmidt & Richardson, 2008).

The effects of music on coordination were different in the two vision conditions, resulting in an interaction of the vision and auditory conditions, $F(2, 391) = 3.27$, $p < .05$. Hearing their partner rock increased participants' coordination over hearing nothing in both the vision and the no-vision conditions, $t = 2.94$, $p < .05$, and $t = 2.40$, $p < .05$, respectively. The effect of music, in contrast, was different depending on whether participants could see each other or not. In the no-vision condition, hearing music had no effect; the music condition did not differ from the no-sound condition, $t = .88$, $p = .38$, and was significantly lower than the rocking-sound condition, $t = 2.06$, $p < .05$. In contrast, in the vision condition, coordination was significantly lower in the music condition than in the vision-alone condition, $t = 2.48$, $p < .05$, or the rocking-sound condition, $t = 4.89$, $p < .001$. To understand why music decreased interpersonal coordination, we examined participants' synchronization with the music.

Synchronization With the Music

Synchronization with the music was above chance ($M = .41$, $SE = .05$), $F(2, 376) = 12.34$, $p < .001$, and did not differ in the no-vision and vision conditions, ($M = .52$, $SE = .05$ and $M = .50$, $SE = .05$, respectively), $t = .96$, $p = .34$. Synchrony with the music remained above chance when trials in which participants synchronized strongly with the music ($r_{xcor} \geq .80$) were removed, demonstrating that synchronization was not due to a small number of trials, $F(2, 347.82) = 5.76$, $p < .01$.

Participants were self-consistent in their degree of synchrony in the vision and no-vision conditions, $r(48) = .90$, $p < .001$. The music remained an attractor whether the sight of their partner rocking provided participants with another source of attraction or not. Unlike coordination, there was no improvement in synchrony across the segments of each trial, $F(2, 376) = 0.02$, $p = .98$, or interaction between vision condition and segment, $F(4, 376) = 0.45$, $p = .78$. Synchronization with the music occurred abruptly, within the first 23 s, and remained steady across the rest of the trial.

Comparison of Coordination With Partner and Synchronization With the Music

For a comparison of synchronization with the music and coordination with the partner, Figure 3 shows synchronization when there was no information about the partner available (no-vision music condition), and coordination between partners when they were exposed to the sound of each other rocking (no-vision rocking-sound condition) and the sight of each other rocking (vision no-sound condition). As expected, coupling was stronger with the other person than with the music, $F(2, 184) = 19.93$, $p < .001$, both when participants could see each other, $t = 6.25$, $p < .05$, and when they could hear each other, $t = 2.36$, $p < .05$. The absence of an effect for segments, $F(2, 184) = 1.25$, $p = .29$, primarily reflects a lack of change in the two auditory conditions, where coupling to both music and the sound of the other person was unchanged across segments, $F(2, 184) = .08$, $p = .93$, and $F(2, 184) = 1.16$, $p = .31$, respectively. Although the Condition × Segment interaction was not significant, $F(4, 184) = 1.68$, $p = .16$, the increase in coordination in the vision-only condition was significant in the earlier analysis of the data in Figure 1, and simple effects for the data in Figure 3 again showed that coordination due to vision improved across segments, $F(2, 184) = 3.38$, $p < .05$.

The bidirectional coupling elicited when dyad members could see or hear each other produced higher levels of coupling than the unidirectional influence of music. There are two possible but not mutually exclusive explanations. The other person may have been more salient than the music in our task. Alternatively, bidirectional coupling may have been easier than unidirectional coupling because both people shared the work involved by accommodating to each other's movements. The continuous adaptation involved in bidirectional coupling also explains the gradual increase in coupling strength when the partners could see each other and the absence of increase for the music. The absence of a corresponding increase in the rocking-sound condition may be attributed to the fact that both chairs made the same sound, making it difficult to distinguish between them.

Correlation of Synchronization and Coordination

Music and the other person both acted as attractors, and coupling with one influenced coupling with the other. When partners

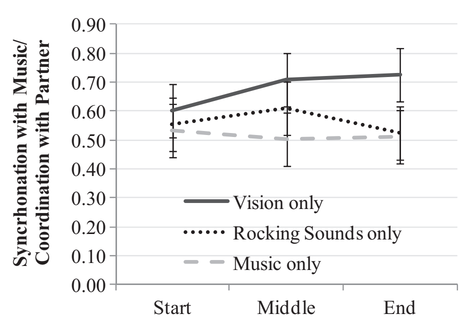

Figure 3. Mean synchronization between participants and music (music-only condition) and between participants and their partners (rocking-sounds-only and vision-only conditions). Error bars indicate ± 1 standard error of the mean estimated by the model.

could not see each other, their degree of synchronization with the music was independent of each other, intraclass correlation (ICC) = .17, $F(47, 48) = 1.41$, $p = .24$, and there was little correlation between coordination and synchronization, $r(46) = .22$, $p = .14$. Partners rocked independently. In contrast, when partners could see each other, their degree of synchronization was strongly related, ICC = .54, $F(47, 48) = 3.32$, $p < .01$, and coordination and synchronization were significantly correlated, $r(46) = .34$, $p < .05$. Seeing each other pulled participants into coordination with each other and into similar levels of synchrony with the music. Rather than complementing each other, however, the sound of the music and the sight of the other person competed as sources of attraction. This is why when music was added to the sight of the other person rocking, coordination decreased rather than increased (Figure 2).

Attribution of Influence of Partner Versus Music

Finally, we looked at participants' answers to questions about how their rocking was affected by their partner and by the music. ICCs assessing the degree of independence between partners' ratings were below chance ($p > .05$) for all questions, allowing us to treat each participant as independent, despite the dyadic design (Kenny, Kashy, & Cook, 2006). Participants reported moderate levels of influence of partner and music (Table 1). To assess the accuracy of these perceptions, we correlated participant's answers to each question with their synchrony with the music and coordination with their partner averaged across trials. The correlations in Table 1 show that participants were unable to accurately gauge their level of coordination with their partners. Reports of coupling between partners were unrelated to the level of coordination actually observed. In contrast, participants' reports of coupling with the music were related to their observed level of synchrony with the music, $r(46) = .37$, $p < .05$. We suggest the difference was a product of the nature of the coupling involved. The bidirectional coupling between partners was less noticeable because both members of the dyad contributed. Unidirectional coupling with the music was more noticeable because each participant had to make all of the changes involved. As result, assessments of how rocking was affected were more accurate for music than for partners.

Table 1
Percentage of Agreement With Each Statement and Correlations Between Agreement and Observed Levels of Coupling With Partner and With the Music

Self-reports of coupling	Agreement (%)	Correlations of coupling with: Partner	Music
We [partners] rocked at the same pace	55.6	.15	.30*
I changed my rocking pace because of the other person	58.7	.06	−.02
The other person changed his/her rocking pace because of me	50.0	.18	.05
I changed my rocking pace because of the music	50.0	.08	.37*
I felt connected with my partner	47.9	.07	.36*

* $p < .05$.

It is interesting that synchronization with the music was correlated with participants' agreement that they had rocked at the same pace as their partner, $r(46) = .30$, $p < .05$. Participants apparently assumed that their partner responded to the music in the same way that they did. The same assumption may have been responsible for the fact that participants who coupled more strongly with the music felt more connected to their partners, $r(46) = .36$, $p < .05$. These results suggest that the well-established finding that coordinating movements with another person produces positive emotions (e.g., Hove & Risen, 2009; Wiltermuth & Heath, 2009) may be a product of one's assumption of having shared a common experience with another person, that is, of both moving to the same music rather than the experience of actually moving in synchrony.

General Discussion

Spontaneous coordination between partners was elicited by either seeing or hearing the other person. Seeing was more effective than hearing, and coordination was highest when both were combined (Bahrick & Lickliter, 2004). Participants spontaneously synchronized their rocking with the music, a unidirectional influence, but less strongly than under the bidirectional influence of seeing or hearing their partner's rocking. Further, music did not enhance the coordination elicited by seeing the other person rock. Instead, music and the sight of the partner rocking competed as sources of attraction. These results support the idea that spontaneous coordination is the product of perceptuomotor processes that are described by the dynamics of coupled oscillators (Kelso, 1995; Kugler & Turvey, 1987; Large, 2000; Richardson et al., 2005) and demonstrate that these processes are not modality dependent.

Although music was the weaker attractor, its effects were more noticeable than the influence of the other person. The flexible bidirectional influence of the partner was apparently too subtle to be clearly identified, while the inflexible unidirectional influence of the music was more noticeable. Music had an additional effect; it provided a kind of social glue. Rocking with the music made participants feel connected to their partners, possibly because they assumed that they were sharing the same experience of synchronizing to the music.

Participants coupled more strongly with their partners than with the music, but it was their experience of coupling with the music that determined how connected they felt to their partners. The power of music to unite people may lie more in its ability to provide them with a common experience than in its ability to coordinate their movements.

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