Interpersonal movement coordination in jointly moving a rocking board

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INTRODUCTION

Most studies of interpersonal movement coordination have, to date, focused on the tacit entrainment of rhythmic motion patterns in tasks that lack any shared action goal (see e.g. Schmidt & O’Brien, 1997; Richardson et al., 2006). In the present study we investigated how subject pairs coordinate their movements when deliberately trying, on a rocking board, to track a visually presented motion pattern. In particular, we asked our subject pairs to jointly produce rocking movements of predefined amplitude-frequency combinations. One of the questions that we addressed - and that is central to the present report - was whether we could differentiate between incidental and deliberate control of the rocking-board movements by the dyads.

In an earlier study in which we focused on amplitude and frequency control in loop writing (Bosga, Meulenbroek & Rosenbaum, 2005) we demonstrated that cycle-to-cycle movement-parameter changes can be categorized as either intentional or biomechanical. Our categorization relied on the inverse relationship that normally exists between amplitude and frequency in that small amplitudes are usually generated at high frequencies whereas large amplitudes tend to be generated at low frequencies (cf. Vaughan et al., 1995). If corrections of amplitude and frequency errors from one movement to the next are negatively correlated, we assume that subjects intentionally changed only one parameter while having exploited biomechanics for the change of the other parameter (cf. Vereijken et al., 1997). Inversely, if such corrections are positively correlated we infer that subjects succeeded in simultaneously, and deliberately, changing both parameters.

To verify whether our paradigm could also be applied to the presently investigated joint-action task, we decided to contrast two conditions that we expected would modulate the extent to which dyads could exert deliberate control over their task performance. In one condition the subjects faced each other and they thus were continuously given both haptic and visual feedback of their and their co-actor’s movement consequences. In the other condition, the two subjects were asked to perform the task back-to-back thus preventing them from seeing each other. In the latter condition, the consequences of the co-actor’s performance could only be picked up haptically. Given the key role which the visual modality is supposed to play in interpersonal movement coordination (Schmidt & O’Brien, 1997; Richardson et al., 2006), the frequency of intentional motion parameter changes was expected to be lower in the back-to-back than in the vis-à-vis condition.

METHOD

Participants

Twenty-eight psychology students from the University of Nijmegen participated in our study. Their age ranged between 22 and 27 years. All participants had normal or corrected-to-normal vision and none had motor problems. All participants gave their informed consent and were
rewarded for their participation with either course credits or payment of 12 Euros. Experimental procedures followed the APA guidelines for the ethical treatment of human participants.

**Task and Procedure**

The participants were randomly paired and given written instructions before the experimental session began. The subject-pairs (dyads) stood on a 200x60 cm wooden rocking board with the base pad covered in non-slip surface as customary used in physiotherapy for proprioceptive training (see Figure 1). The board with a 30 degree tilt could only rock in one dimension (x-dimension). Each participant performed side-to-side rocking movements in nine conditions covering three amplitudes (8, 18 and 28 degrees) and three frequencies (0.4, 0.6 and 0.8 Hz). Furthermore the task was executed by each participant individually or as a dyad. When together, they were placed in two different stances viz.: vis-à-vis (seeing each other) and back-to-back (not seeing each other). The instructed and realized amplitude-frequency combinations were presented real-time on computer displays in the form of rotating bars. Participants were asked to track the target movements by jointly rocking the board sideways while receiving continuous visual feedback of its rotations. They were not allowed to communicate verbally with each other. Before the experiment started, participants were allowed to practice the task a few times to get comfortable with controlling the movements of the rocking board.

The 30-s trial started when the target bar began to tilt and ended when the target bar ceased to rock. Each experimental session consisted of four blocks of 27 trials leading to a total of 108 trials for each session. The first and fourth trial block was always a joint-action condition be it the participants facing each other or standing back-to-back. In the second and third block the participants performed individually. All blocks were counterbalanced across the experiment. By structuring the sessions in this manner, participants were spared to perform more than 54 trials in succession. Each block consisted of three repetitions of the nine amplitude-frequency combinations that were presented at random.

**Data acquisition**

Three rigid bodies, each consisting of four infrared light emitting diodes (IREDs) fixated at a 1 x 1 x 1 cm inter-IRED distance on a flat aluminum plate were consecutively mounted on the base pad of the rocking board and strapped onto the foreheads of each participant. Next, 16 infrared light emitting diodes were attached to the ankles, knees, hips, and upper trunk (over the Coracoid process) of each actor. Translations of the IREDS and rotations of the rigid bodies were recorded at a rate of 75 Hz and with a spatial accuracy higher than 0.2 mm in the x, y and z direction by means of a 3D-motion tracking system (Optotrak 3020, Northern Digital Inc., Waterloo, Canada). At the same time, the instructed and realized angular rotations of the rocking board were sampled real-time at a rate of 38.7 Hz and recorded into a separate file. The intrapersonal coordination captured by the recording of the IREDs on the participants’ bodies was
not analyzed for the purpose of the present paper. The results of those analyses will be reported elsewhere.

**Data Analysis**

The instructed and realized angular rocking movements were resampled to 75 Hz and filtered with a second-order, dual-pass Butterworth filter. The high-pass frequency was 0.5 Hz for all signals and the low-pass cut-off frequency of the filter was set to twice the pacing frequency of the condition in which the signal was recorded. This ensured that an automatic peak-peak detection algorithm could be applied reliably. On the basis of this algorithm, successive cycles were extracted of which the first and last cycle of the trial were not included in the analysis.

For each obtained rocking cycle, the realized amplitude \( A \), expressed in mm, in the x-dimension was calculated. A similar procedure was applied to arrive at a local cycle frequency, \( F \), expressed in Hz. Next, the parameters \( A \) and \( F \) were used to calculate the local spatial error, \( A_{err} \), expressed as a percentage of the instructed amplitude, where positive values reflected amplitude overshoots and negative amplitudes reflected amplitude undershoots. Similarly, the local frequency error, \( F_{err} \), was expressed as a percentage of the instructed frequency, where positive values reflected higher than instructed frequencies and negative values represented lower than instructed frequencies. The next step concerned quantifying the error changes from one cycle to the next. Except for the first movement cycle in each trial, we obtained for each cycle, the two parameters \( \Delta A_{err} \) and \( \Delta F_{err} \), where \( \Delta A_{err} \) equaled \( A_{err} \) of cycle \( i \) minus \( A_{err} \) of cycle \( i-1 \), and \( \Delta F_{err} \) equaled \( F_{err} \) of cycle \( i \) minus \( F_{err} \) of cycle \( i-1 \).

A minimum value, \( d \), set at 1% of the local instructed parameter value, was used to identify a change in parameter value. Any absolute value greater than or equal to this value qualified as a parameter-value change. We first categorized the \( A_{err} \) and \( F_{err} \) data into the eight outer (quantitative) cells of Table 2. These eight categories represented all possible combinations of overshoots and undershoots in the amplitude and frequency domain. Subsequently, each \( \Delta A_{err} \) and \( \Delta F_{err} \) combination, representing the error change realized from one movement to the next, was classified as a single-parameter change or as a double-parameter change or as a quasi-double parameter change.

The critical value for statistical significance was set at the .05 level. Sign tests were used to evaluate the statistical significance of observed differences between the incidences of movement-error categories and categories of parameter changes. These non-parametric tests were more conservative than Chi-square tests in this context. Repeated measures ANOVAs were applied to evaluate the continuous movement parameters.

**RESULTS**

*Realized amplitudes and frequencies*

All dyads produced, on average, the instructed movement amplitudes and frequencies accurately (see Table 1). As expected, the realized amplitudes decreased somewhat as the imposed frequencies increased (\( F(2,26)=15.12, p<.01 \)). The reverse was not true, however. The realized frequencies slightly increased as the imposed amplitudes increased (\( F(2,26)=4.76, p<.05 \)). We will return to this deviating finding in the discussion.
All fourteen dyads produced a total of 19,734 movement cycles that were evaluated in terms of the realized amplitude and frequency relative to the instructed amplitude and frequency. Table 2 shows the frequency distribution of performance errors categorized per cycle but collapsed over the three instructed amplitude and frequency conditions. At the center of Table 2 the proportion of movements for which both the amplitude and frequency were on target. Note that, as expected, this number is low because of the stringent criterion we used to identify errors and error changes (i.e., 1% of each of the two goal parameters, see Method section). As expected, 12 out of 14 dyads produced more amplitude undershoots than amplitude overshoots (sign test, N=14, p < .05; cf. Gordon et al., 1995) whilst all 14 dyads produced more frequency overshoots than frequency undershoots (sign test, N=14, p < .001).

Table 2. Incidence (%) of amplitude and frequency errors with the mean sizes of the errors between parentheses.

<table>
<thead>
<tr>
<th>Parameter changes from one movement to the next</th>
</tr>
</thead>
</table>
| Table 3 shows the three types of parameter changes: single when either the amplitude or frequency changed from one cycle to the next, double when both parameters changed into the same direction, and quasi-double when one parameter increased and the other decreased or vice versa. Table 3 shows the incidence of the three types of parameter change as a function of the three categories of error changes (increase, increase/decrease, and decrease) expressed as a percentage of the local goal parameter. The latter factor reflects whether the parameter changes were goal-directed (increase) or not (decrease).
In general, participants obeyed the task instructions by trying to satisfy either one or both the requested amplitude and frequency constraints. From one movement to the next they succeeded in changing local movement parameters toward the goal movement parameters. Thus, all 14 dyads produced more movements that reduced either one or both parameter error(s) than movements that caused both local movement parameters to drift away from the goal parameter combination (sign test, N=14, p < .001).

All 14 dyads produced more quasi-double parameter changes (52.64%) than double parameter changes (26.95%; sign test, N=14, p < .001) or single-parameter changes (17.95%; sign test, N=14, p < .001) whilst 12 dyads produced more double than single parameter changes (sign test, N=14, p < .05).

Table 3. Frequency table of parameter changes (single, double, quasi-double; see text). The row factor (Error change) reflects whether the changes were goal-directed (increase) or not (decrease).

<table>
<thead>
<tr>
<th>Type of parameter change</th>
<th>Single</th>
<th>Double</th>
<th>Quasi-double</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase</td>
<td>5.90%</td>
<td>7.47%</td>
<td>13.30%</td>
<td>26.67%</td>
</tr>
<tr>
<td>Increase &amp; Decrease</td>
<td>4.91%</td>
<td>10.84%</td>
<td>21.29%</td>
<td>37.03%</td>
</tr>
<tr>
<td>Decrease</td>
<td>7.14%</td>
<td>8.63%</td>
<td>18.06%</td>
<td>33.83%</td>
</tr>
<tr>
<td>Total</td>
<td>17.95%</td>
<td>26.95%</td>
<td>52.64%</td>
<td>97.54%</td>
</tr>
</tbody>
</table>

Parameter changes independent of available modalities

Figure 2 shows the absence of any effect of the key experimental manipulation of the participants either facing each other or rocking the board back-to-back on the frequency distribution of cycle-to-cycle parameter changes. The results do not confirm our hypothesis. Even though shown in Fig. 2 by means of a cumulative count, the finding held for all dyads (sign test, N=14, p < .001).

Figure 2. Frequency of movement-parameter changes. Quasi-double parameter changes outnumber other types of cycle-to-cycle parameter adjustments, both in the condition in which the participants faced each other and in which they performed the task back-to-back.
DISCUSSION

The present findings confirm that also in joint motor tasks in which two actors share an action goal explicitly, people manage to exploit the biomechanical relationships between movement amplitude and frequency when asked to generate specific target values of these parameters. While rhythmically moving the rocking board sideways, energy optimization most likely prompted the dyads to stick to a general strategy of amplitude undershooting. This is in line with the findings by cf. Gordon et al. (1995). The presently selected movement frequency range elicited overall frequency overshoots, probably because the preferred frequency of the rocking board, with two adults balancing on top of it, was higher than we inferred during the piloting phase of this study. The latter might also be the cause why the realized frequencies increased with an increase of the imposed amplitudes.

As regards movement-parameter changes from one movement to the next, the present study confirms our earlier findings obtained in a study of a totally different motor task, viz., loop writing (Bosga et al., 2005). When categorizing cycle-to-cycle movement parameter changes hovering around a target parameter combination, people, also when performing a complicated motor task together, manage to exploit the biomechanical relationships of motion amplitude and frequency. In other words, they most often focus their intentional movement change on one aspect of the task and try to get the change in another task dimension for free. It is this strategy that yielded the largest incidence of quasi-double movement parameter changes from one cycle to the next.

The null results of the present study that the adopted parameter-change strategy did not vary as a function of whether the participants saw each other while performing the task or not, are, in our view, informative (cf. Harcum, 1990). They demonstrate that exploitation of biomechanics in goal-directed task performance is a prominent motor control mechanism that seems to be independent of the modalities used for monitoring the perceptual consequences of the generated motion patterns. Whether or not modality-dependent variations occurred with respect to intra- and interpersonal joint coordination, where joint now refers to the linkage between neighbouring limb segments, remains a matter for future analysis.

REFERENCES


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