Motion Primitives of Dancing

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Abstract. In this work, we analyze whether oscillatory motion between two extreme positions could be used to create a robotic dancing partner that provides natural haptic feedback. To this end, we compared the pattern of hand movements performed following a pacing signal while participants were instructed to either move rhythmically or to dance. Furthermore, we analyzed the influence of the frequency and type of pacing signal on the two kinds of movements. Trajectories were analyzed in terms of: frequency of movement, spatial and temporal synchronization, and jerk.

Results indicate that it is easier to perform synchronized movements while dancing, even though these movements partially deviate from the pacing frequency. Dance movements are in fact more complex than the ones produced to keep the rhythm and for this reason they should be modeled accordingly in order to provide realistic haptic feedback.

Keywords: Dancing, Rhythm, Frequency, Trajectory, Position error, Time shift, Jerk.

1 Introduction

Dance refers to body movements in accordance to music, with characteristics that extend pure rhythmic motion between two extreme positions. Dance movements reflect the hierarchically arrangement of strong and weak tones in the music [1], are intrinsic motivated [2], and involves some extra qualities (e.g. interaction, expression, and entertainment).

This paper is an attempt to identify the primitives of dancing movements that can be implemented on a dancing robot. Since a dancing simulation requires realistic haptic feedback, here we asked whether the results of the numerous studies on cyclical rhythmic task could be generalizable to dancing and applied to reproduce an accurate dance feedback. In a cyclical rhythmic task (e.g. [3] and [4]) people are instructed to move between two positions while following a pacing signal (usually a metronome which gives a beat to synchronize movements

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to). In the present study, we compare the trajectories of cyclical and dancing movements in order to evidence differences between them. Moreover, we investigated how dancing trajectories depend on the type of pacing signal. Pollatou and Hatzitaki [5] compared peoples' capability to synchronize to a metronome and a piece of music, showing that performance was better with a metronome. We hypothesize that this difference might be due only to the requirements of a rhythmic task, and therefore be absent in dancing. Finally, we analyze the influence of the pacing signal's frequency on the movement produced. For example, [4] and [6] showed that frequency influences synchronization performance. Here we want to understand whether this factor has the same effect in dancing.

To reduce the complexity of dancing in this study, participants performed arm movements. Our rationale for this choice is that if we find a difference between rhythmic and dancing movements in this reduced situation, this difference would be present in any other type of settings because intrinsic of dancing tasks. Moreover, this type arm movement was partially consistent with the tasks adopted in rhythm production studies, where small movements are often performed (i.e. finger tapping as in [6]).

2 Method

The actuated Thrusttube linear device with one degree of freedom was used as input device (figure 1). The controller was implemented using the Realtime Workshop of MATLAB/Simulink in conjunction with the Real Time Application Interface on a standard Linux PC. An admittance control scheme rendered a virtual mass of 1.5 kg at 1 kHz. Two red markers 80 mm apart indicated the required amplitude of movement. These spatial constrains are introduced because otherwise the complexity of data is to exaggerated for understanding motion primitives of dancing. Participants sat approximately 40 cm in front of the device. Participants wore noise reduction headphones and white noise was played throughout the experiment.

A $2 \times 4 \times 2$ within-subject design was used, with two task-conditions (dancing task, rhythmic task), four type of signal-conditions (LED, metronome, Music 1 "Tears In Heaven", and Music 2 "All I Wanna Do") and two frequency-conditions (79 beats per minute, 1.32 Hz, and 122 beats per minute, 2.03 Hz). In the first block of the experiment, participants were instructed to move their arm on the

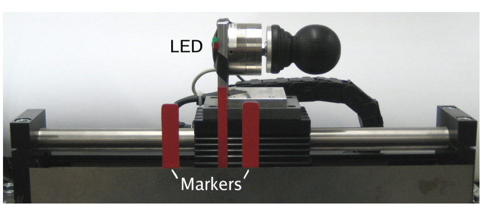

Fig. 1. Linear input device

linear device as they were dancing to the given pacing signal (dancing task). In the second block, participants move their hand in an oscillatory fashion in order to be at one of the two markers at each of the beats (rhythmic task). We chose a within-subject design because a pre-test revealed high interpersonal difference in the interpretation of the pacing signal. Within each block, the four types of pacing signal at each of the two frequencies were presented in randomized order. One trial lasted sixty seconds, but only the data collected between 15 and 55 seconds was analyzed.

Eleven participants took part in this study (6f, 5m), all but one played at least one instrument. Mean age was 25.09 (ranging 22 to 28). Participation was voluntary. One participant had to be excluded from further analysis because it did not follow the instructions.

A spectral analysis of position over time indicated that participants did not always move with the same frequency of the pacing signal. Hence, we estimated the executed frequency in a trial by computing the time proportion at which subjects performed movements at three frequencies: expected frequency (the frequency of the pacing signal), half of the expected frequency, and other frequencies. The first two groups had a range of ±20 % of the pacing signal. Since extremes in the trajectories generated by the participants (turning points) had to be synchronized with the beats, in order to characterize subjects' performance in relation to the pacing signal we only further analyzed turning points within one quarter period before and after the beat (8023 of 11847 turning points were analyzed across participants).

From the remaining position data, we computed three measurements. Differences in the position between the turning points and the two markers were analyzed by calculating the position error according to $\Delta x_i = |x(t_{tp,i})| - 40\,\text{mm}$, where tp denotes the turning point and i the current beat. Time accuracy was defined as the time shift between the turning point and the beat $\Delta t_i = t_{tp,i} - t_{beat,i}$. Finally, jerk was computed between the zero crossing before and after each turning point by calculating the time integral of the squared jerk [7] after smoothing the recorded trajectory using a fourth order Savitzky-Golay filter with a window of 33 samples:

$$J_i = \frac{1}{2} \int_{t_{beat,i} - \frac{1}{4}T}^{t_{beat,i} + \frac{1}{4}T} \dddot{x}^2(\tau) d\tau,$$

where $\pm\frac{1}{4}T$ was used because turning points could be close to either one of the two markers.

3 Results

The influence of the task on the percentage of correct frequency was analyzed using a Wilcoxon signed-rank test. Correct frequencies were significantly higher in the cyclical task (mean=80.15) than in dancing (mean=44.81), $[T = 0; p < 0.001, r^2 = 0.781]$, which is coherent with task instructions. The frequency of the pacing signal did not influence the frequency at which movements were performed. The relationship between experimental conditions and frequency groups

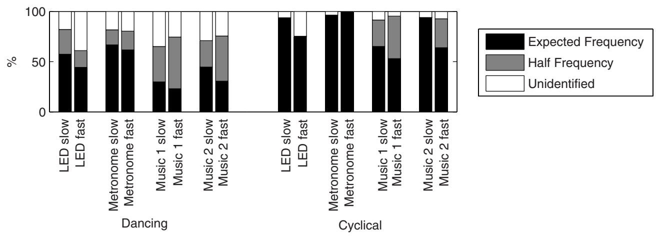

Fig. 2. Percentage of the trial that contained participant's motion at one of the three grouping frequencies: expected frequency (specified by the pacing signal), half of the expected frequency, or any other frequency

is given in figure 2. Friedman's ANOVA revealed a significant effect of the type of signal on the frequencies performed [$\chi^2(3) = 14.06, p < 0.001$]. The percentage of the trial containing movements at the correct frequency was highest for the metronome condition and lowest for the two music conditions.

Because the values of position error, time shift, and jerk did not correlate in our data, we executed univariate tests. ANOVAs (table 1) reveal that the task performed influenced jerk and time shift.

Dancing led to higher jerk and lower time shifts as illustrated in figure 3. The type of signal influenced position error and jerk (descriptive for type of signal and frequency are shown in tables 2 and 3).

A Bonferroni corrected pairwise comparison showed significant differences between the metronome and the other type of signals (metronome led to significantly lower jerk). The same test showed that with LED and music 1 pacing signals, participants' motion was performed with higher position errors. The type of signal did not have any effect on time shift. The frequency of the pacing signal influenced the time shift for both task, where at lower frequencies turning points anticipated the beat and at high frequency they happened afterwards. Interaction of task and frequency on time shift reaches significance because in cyclical tasks the effect of pacing signal's frequency on movements is greater than in dancing.

Table 1. Significant factors (task performed, type of pacing signal, and frequency of the pacing signal) and interactions obtained in the ANOVA for each of the measures computed on the performed trajectories (*Greenhouse-Geisser corrected)

Measure	Factor	Test Statistic	p	partial η^2
log. jerk	task	$F(1, 9) = 7.690$	0.022	0.461
log. jerk	type	$F(3, 27) = 11.704$	< 0.00	0.565
log. jerk	type*freq	$F(3, 27) = 4.338$	< 0.013	0.325
time shift	task	$F(1, 9) = 9.825$	0.012	0.522
time shift	freq	$F(1, 9) = 17.004$	0.003	0.654
time shift	task*freq	$F(1, 9) = 7.325$	< 0.024	0.449
position error	type	$F(1.467, 25.571)^* = 8.451$	0.0097	0.484

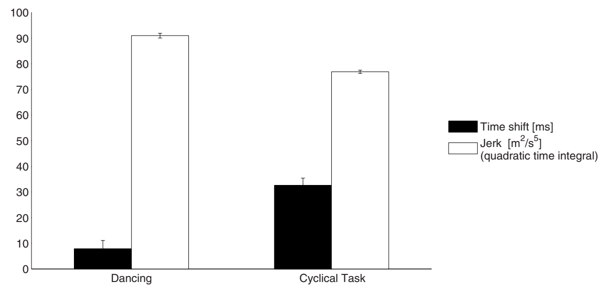

Fig. 3. Significant effects of task (mean and standard error)

Table 2. Effect of the type of pacing signal on position error and jerk: mean and standard deviation

	LED	Metronome	Music 1	Music 2
position error	0.006 (0.007)	0.003 (0.004)	0.003 (0.004)	0.003 (0.004)
log. jerk	1.884 (0.232)	1.781 (0.004)	1.889 (0.235)	1.864 (0.234)

Table 3. Effect of the frequency of the pacing signal on time shift: mean and standard deviation

	slow	fast
time shift	0.0978 (0.223)	−0.029 (0.148)

4 Conclusion

Dancing movements can be distinguished from the ones performed during other cyclical tasks. First, it is easier to perform movements in accordance to the beat and without synchronization errors while dancing. Second, dancing movements are performed at different frequencies than the one composing the pacing signal to synchronize to (either a LED, a metronome, or a piece of music). Third, jerk is higher while dancing, which seems natural because dancing movements are not bound to efficiency and involve some additional pattern of movements.

These three findings lead to the conclusion that participants interpret dancing as an oscillating movement between two positions, but this movement necessarily involved movement variations or deviation from the basic rhythm. Time shift is affected by pace, but synchronization is better in the dancing conditions. The good synchronization performance during dancing can be thought as intuitive handling of timing patterns while dancing. The relevance of time in a dancing task does not weaken the position accuracy, as there is no significant difference between the tasks in this measure. Moreover, the low time shift in dancing together with the equal amount of position error while performing cyclical tasks indicates that the order chosen for the two task did not affected participants' movement. In fact, if any learning would have occurred during experiment the time shift and position error would have been smaller in the second block of the experiment (which contained only cyclical task trials) while instead it was the opposite. Motion primitives are additionally influenced by other factors, for example the type of signal (LED and music led to higher jerk). This result is consistent with the view that music as well as dancing provokes more playful movements than a metronome or cyclical task do.

The aim of this work was to start the characterization of dancing movements while moving along a constrained trajectory in order to create a virtual dancing partner. We could identify some motion primitives that significantly differ in the production of a dancing movement versus a cyclical movement. This difference could be used in the creation of a realistic haptic feedback, although more analysis is required. In this regard, we intend to continue this investigation by analyzing the interaction of two partners.

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