Kinesthetics of dancing vs. cyclical movements

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Abstract. In this work, we analyzed and compared two patterns of movement according to a rhythmic signal (dancing vs. cyclical rhythmic movements) to create a more natural virtual dancing partner with haptic feedback. We observed linear movements to reduce the analysis complexity and highlight the critical factors that can be generalized to unconstrained movements. Results indicate that dancing movements are performed at lower frequency of oscillation than the provided signal. However, synchronization errors are lower during dancing, indicating that dance is a more natural and easy way to perform the task. Finally, the amount of jerk is higher while dancing, indicating that dance movements are not inherently smoother, but are instead more complex than cyclical ones.

Key words: Dancing, Rhythm, Frequency, Trajectory, Position error, Time shift, Jerk

1 Introduction

This work analyzes the defining characteristics of dancing movements and it is intended as the first step in the analysis of dance for the purpose of creating a virtual dancing partner. Providing realisitc movement trajectories is in this context crucial for developing a natural dance interaction. Therefore, a model of a dancing person is a key prerequisite. Dance refers to movement of the body in a rhythmic way and in accordance to music. The movements that make up dance are not reducible to those of straightforward oscillating between two positions, but they involve some extra qualities (communication, expression, interaction or pleasure).

Dance movements tend to be organized into spatial and temporal sequences, creating rhythm, which is also a basic element of music. Cyclical rhythmic tasks have been used to investigate similar instances. In these tasks, people often move in synchrony with auditory rhythms [1]. In a cyclical rhythmic task, people move from one position to another while respecting the signal which paces their expected time of arrival at this position. This task requires that movements in the period between two signals are organized in the appropriate way, as a coordination to an external rhythmic signal [2]. With respect to the present study, the question we investigate here is how trajectories of dancing movements differ from those of cyclical rhythmic movements. Our expectation is that dancing movements have other requirements in addition to the temporal synchrony of a rhythmic task, therefore the movement performed in the two tasks should be different in some respect. In this paper we identify some of the parameters that differ in the rhythmic behavior when performing the two tasks (cyclical rhythmic task and dancing) while keeping all other parameters fixed.

Despite the relation existing between music and motion, while testing whether rhythmic beats only or music would be more effective as accompaniment for the motor performance of specific rhythmic-dance steps, [3] found that beginners performed much better in terms of movement synchrony when they are guided by a rhythmical sequence of single beats than when guided by a musical phrase having identical metrical structure. In the context of the present study, it is important to investigate whether the modality used to produce the rhythmic pattern does influence the trajectories of dancing movement as well.

In addition, dance movements modify time perception: which is affected by the rhythmic ordering of movement, by the duration of the dance, and by the time content of the music [4]. Phillips-Silver and Trainor [5] demonstrated an early cross-modal interaction between body movement and auditory encoding of musical rhythm in infants. Both adults and infants identify an ambiguous beat as being similar to an auditory version of the rhythm pattern with accented beats that match their movement [4]. In the context of this study, we expect that dancing movements differ from cyclical beat following; this in turn should change perceived time of the temporal pattern, therefore influencing the synchrony at which movements are performed.

2 Hypotheses

In order to obtain a simulation of a dance with a virtual partner we need to identify the basic characteristics of movement performed while dancing. To do this, we simplified the task given to the participants by reducing the motion to the simplest type possible, the movement of one arm while the hand is constrained to move on a linear trajectory. While this task limits the complexity of motion in free space typical of normal dance movements, it preserves the freedom of generating different types of motion and the possibility of kinesthetic interaction (which are required to negotiate a common trajectory in paired dances).

Participants were required to either (1) move their arm in synchrony or (2) to dance to a rhythmic pattern while holding the handle of a linear device. Their movement was also required to end at two points marked on the device. Because we assume that music facilitates dancing, we investigated the influence of the modality by which the rhythmic pattern is provided; we compared the effect of two pieces of music, with only rhythmical beats: a simple metronome (monotonic beat) and a blinking LED (40 ms on-time). Because music perception is a complex process with influences that range from low level sensory signals to cognition and even emotional responses [6], it is difficult to classify music in a purely objective manner. We therefore utilized only two different pieces of music to take this aspect into account, without trying to provide an extensive characterization of this factor on dance movements. Moreover, because other studies revealed an influence of the pace of the rhythm, we also compared two different frequencies of the signals above. The defining characteristics of trajectories were obtained using different measurements: frequency, position and time accuracy, and jerk. Each measurement highlights certain characteristics of the movements, and their integration gives an overview of the characteristics of dancing versus rhythmic motion. Frequency of the rhythmic movement is essential to understand whether the synchronization to the rhythmic pattern is accurate. With correct synchronization, the frequency of the rhythmic pattern and of movement should be identical. Jerk, the third derivative of position with respect to time, characterizes the amount of control in performing movements. It has been used extensively in pointing task for this purpose, where it has been shown to be related to the amount of skill in the performance of motor acts [7] because it is inversely related to the smoothness and efficiency of motion patterns [8].

On the basis of the theoretical background, we analyzed the following hypotheses:

H1: Dancing is fundamentally different from simply performing rhythmic movements. In dancing, lower timeshift is expected in keeping the beat. Position errors are expected to be lower in the rhythmical movement condition because dancing is defined by timing patterns and it is less constrained on position of the movements; moreover the participant is performing a task that requires an additional component, smoothness and expressiveness of the movements. So, jerk is lower in dancing.

H2: There is a difference in the trajectories in dependence of the modality of rhythm instruction. With music, position error and time shift are smaller than in the other conditions because more information between the signals is presented, the timing of the between position movement is easier. With LED the position error and time shift are larger than in the other conditions because according to [1] sound has higher accuracy in specifying a rhythmic pattern and support more accurate performance. The jerk is higher in the LED and the metronome condition than in the music conditions because music invites to smoother movements than monotone signals. Frequency of movement is more accurate in the music condition because more information is provided between the two determining beats. Furthermore, we expect an interaction between task and modality as dancing should differ more from cyclical tasks when music is involved.

H3: There is a difference between slow and fast paced rhythms. With lower frequency in the rhythm position and timing error are lower because there is more time to actuate the movement correctly, jerk is higher with higher frequency because there is not enough time to perform smooth movements.

Frequency is more accurate when the pace of the rhythm is lower because there is more time to perform the movement. In accordance with [7] we expect an increase of jerk with higher frequencies.

3 Method

A linear arm movement was chosen to identify primitives of dancing movements. In this way, we reduced the complexity of the scenario and made a comparison to cyclical movements possible. The linear input device which recorded the position over time is pictured in figure 3. The two red bars marked the instructed turning

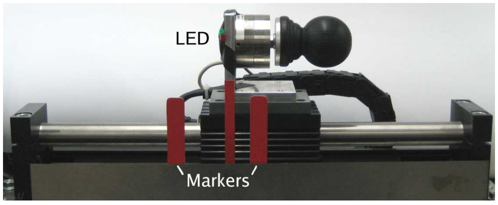

Fig. 1. Linear input device.

points of the movement. The rhythm to which the participants had to move was constant and given in three different modalities: with a LED, with an audio metronome, or with a piece of music.

3.1 Experimental Setup

The actuated Thrusttube linear device with one degree of freedom was used as input device. Participants sat on a chair in front of the device with approximately 40 cm distance. To compensate the friction of the device, an admittance control scheme rendered a virtual mass of 1.5 kg at 1 kHz. The position of the input device was recorded at the same frequency. The actuation was introduced here to record comparable data for future setups involving two persons and haptic rendering. The controller was implemented using the Realtime Workshop of MATLAB/Simulink in conjunction with the Real Time Application Interface on a standard Linux PC.

The two red position markers, between which the movement should take place, were 80 mm apart from each other. The rhythm in the LED condition was given by two LEDs mounted on the handle of the device. The three auditory stimuli were presented via noise reduction headphones. In all four conditions white noise was played additionally via the headphones. In this way, we damped the noise motions produced by the linear device. The pace within the slow and fast conditions was equal for all four modalities of rhythm instruction.

The two pieces of music determined the slow and fast pace. For the slow song (Music 1), "Tears In Heaven" was chosen which has 79 beats per minute

(0.76 Hz), the fast song (Music 2) was "All I Wanna Do" at 122 beats per minute (0.49 Hz). Both songs were adapted to the other pace by adjusting the MIDI velocity. The two tempi of the LED blinking and the metronome were constructed in accordance to this paces.

Eleven participants took part in this study. All of them played at least one instrument, except for one. Six participants were female, five male. The mean age was 25.09 ranging from 22 to 28. Participation was voluntary.

3.2 Procedure

After reading the instructions, participants had sixty seconds to familiarize with the device and the task. A piece of music not being part of the actual experiment was presented and the LED was flashing according to the beat.

In the first block of the experiment, participants were instructed to dance with linear arm movements to the given rhythm. In a second block, instructions required participants to be at one position when the rhythmical signal occured. The order of the blocks was not randomized to make sure that the dancing block was not influenced by the instructions for the metronome task. Within these two blocks, all four modalities of rhythmic instruction were presented in both paces. The eight conditions per block were featured in random order to each participant. One trial lasted sixty seconds.

Between the two blocks of the experiment, we introduced an additional test trial to make sure that participants fully understood instructions in the cyclical task. This trial was repeated, until the experimenter identified correct performance.

3.3 Data Analysis

In order to avoid artefacts, only the data collected between 15 and 55 seconds of each experimental trial was analyzed. Measures that were more than two standard deviations away from the mean value across all conditions, were excluded as outliers. Since the turning points in position (peaks of trajectory), had to take place at the moment where the rhythmic signal was played back for each beat, only turning points which lay within the interval of one half of the time difference (time from one beat to the other) to the beat before and after the according signal were included in the analysis. Turning points result as peaks in the trajectory. The position error was analyzed through the peak value. The time accuracy was determined by calculating the time shift between the detected peak and the presented stimulus. Jerk was analyzed between the zero crossing before and after each detected peak by calculating the time integral of the squared jerk [8]. The recoded position signals were smoothed and derivated using a fourth order Savitzky-Golay filter with window of 33 samples.

In the statistical analysis we consider the following three within-subjects factors which were modelled in a full factorial design. Task (2 levels): dancing or cyclical task. Modality of the rhythmic signal to be followed (four levels):

blinking LED, audio Metronome, Music 1 and Music 2. Pace (2 levels): slow (0.76Hz) or fast (0.49Hz).

4 Results

A spectral analysis of position over time revealed that participants were not always able to generate the externally induced frequency in their movements, see figure 2. Therefore, we estimated the frequency in the position signal assigned to a beat by measuring the lag to the successive detected beat. Data across all conditions was subdivided into three groups. We categorized the frequency into the expected one and half of the expected frequency, both allowing a variance of 20 % per peak, and a group not matching any of these two frequencies. If more

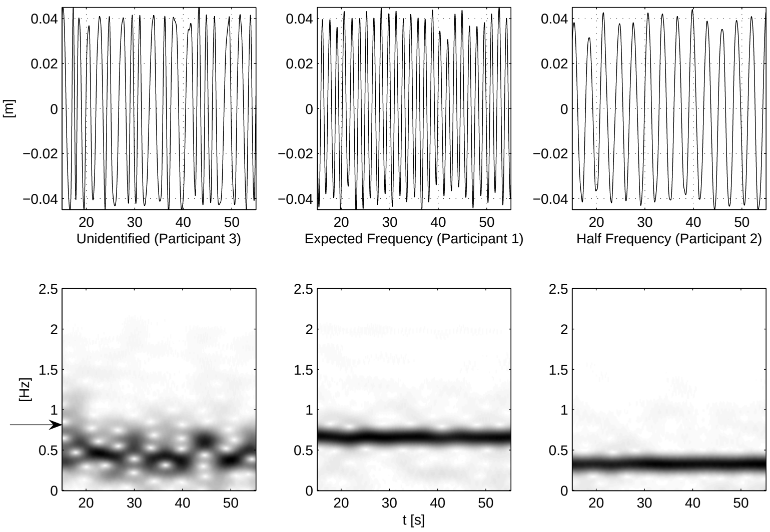

Fig. 2. Three exemplary participants. Position over time in the upper part, spectrum in the lower part.

than 75 % of the beats was accomplished using the same frequency type, this trial was grouped into the corresponding three frequency group for each participant independently. One participant had to be excluded form further analysis because it did not follow the instructions. Friedman's ANOVA revealed a significant effect of the factor modality on the percentage of correct frequency actuated in these trials ($\chi^2(3)$=14.06, p=0.001). The percentage of correct frequency was low for the metronome condition and increrased for LED and music 2, reaching highest values in the music 1 condition. Additonally the influence of the task on the percentage of correct frequency was analysed 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 same test did not reach significance when the influence of the pace on frequency was examined. The relationship between experimental conditions and frequency groups is given in figure 3. To describe the influence

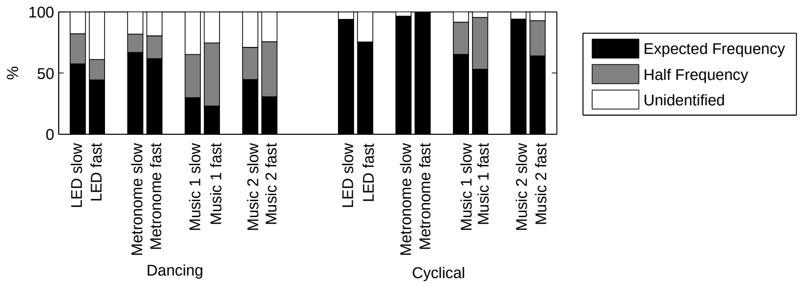

Fig. 3. Average percentage of the trial that contained participant's motion at the expected frequency (the frequency specified by the rythmic pattern) at half of it, or at any other frequency.

of the three factors on position error, timeshift and jerk, we analyzed deviation from the moment of beat occurrence (time shift), deviation from the correct position (position error) and the time integral of jerk. For jerk, we analyzed the logarithmic values to achieve normally distributed data.

Because the three independent measures correlate extremely low or not at all (timeshift*position error: $r = 0.011$, $p(\text{two} - \text{tailed}) > 0.05$; position error*jerk: $r = 0.062$, $p(\text{two} - \text{tailed}) < 0.000$; timeshift*jerk: $r = 0.050$, $p(two - tailed) < 0.000$), we interpret univariate tests. ANOVAs reveal that the task factor influences jerk (logarithmic jerk in dancing: mean=1.887, sd=0.249; in cyclical task: mean=1.829, sd=0.219; $F(1, 9) = 7.690$, $p = 0.022$; partial $\eta^2 = 0.461$) and timeshift (timeshift in dancing: $mean = 0.008$, $sd = 0.192$; in cyclical task: $mean = 0.033$, $sd = 0.192$; $F(1, 9) = 9.825$, $p = 0.012$; partial $\eta^2 = 0.522$). The factor pace has an effect on timeshift only (timehift in slow pace: $mean = 0.0978$, $sd = 0.223$; in fast pace: $mean = -0.029$, $sd = 0.148$; $F(1, 9) = 17.004$, $p = 0.003$; partial $\eta^2 = 0.654$). Whereas as the modality factor influences the position error (position error in LED: $mean = 0.006$, $sd = 0.007$; in metronome: $mean = 0.003$, $sd = 0.004$; in music 1: $mean = 0.003$, $sd = 0.004$; in music 2: $mean = 0.003$, $sd = 0.004$; $F(1.467, 25.571) = 8.451$, $p = 0.0097$; partial $\eta^2 = 0.484$; Greenhouse-Geisser corrected) and jerk (logarithmic jerk on LED: $mean = 1.884$, $sd = 0.232$; in metronome: $mean = 1.781$, $sd = 0.004$; in music 1: $mean = 1.899$, $sd = 0.235$; in music 2: $mean = 1.864$, $sd = 0.234$; $F(3, 27) = 11.704$, $p < 0.000$; partial $\eta^2 = 0.565$). Figure 4 illustrates the significant effects of task. The jerk is higher when participants danced in comparison to cyclical tasks, so this part of hypothesis 1 has to be rejected, we found the opposite than expected. On the other hand, timeshift was generally lower in dancing than in cyclical tasks as was assumed in hypothesis 1. The here expected difference in the position error in dancing and cyclical tasks could not be found. A Bonferroni adjusted pairwise comparison for modality showed signifi-

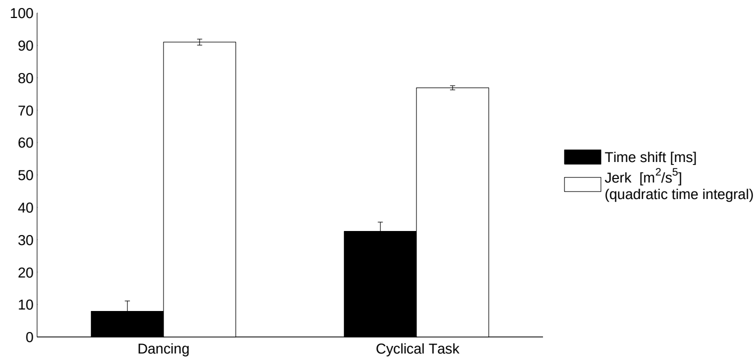

Fig. 4. Significant effects of task (mean and standard error).

cant differences between the metronome and the other conditions, because the metronome leads to significantly lower jerk compared to the other modalities. This is different than expected in hypothesis 2. For the position error the same test showed a significant difference only between the LED condition and music 1. With LED, participants had generally higher position errors. We expected this to be true for the metronome condition as well in hypothesis 2. Modality did not have any effect on timeshift, so we can not support this part of hypothesis 2.

In slow trials participants moved too fast meaning that they performed with negative timehsift, arriving at the position too early. For fast trials it was the other way round, people arrived too late at the position. The absolute amount of timeshift was smaller in the latter ocondition. Therefore we have to reject hypothesis 3, because timeshift was not lower with lower frequencies and position error as well as jerk were not effected by pace.

The following interaction reached significance: task*pace for timeshift $F(1,9) = 7.325$, $p < 0.024$; partial $\eta^2 = 0.449$) and modality*pace for jerk $F(3,27) = 4.338$, $p < 0.013$; partial $\eta^2 = 0.325$). Pace in interaction with the modality is effecting jerk, for the faster pace leads to lower jerk except for the music 2 condition were it is the other way round. The slow pace leads to lower timeshifts in both tasks in comparison with the fast pace. Interaction of task and pace on timeshift here reaches significance because in cyclical tasks the difference is clearer than in dancing.

5 Conclusion

When compared with cyclical rhythmic motion, dancing is less constrained by external information and has other influencing factors. According to this view, our goal was to define the the characteristics of dancing trajectories contrasting other cyclical movements. We found that participants follow less accurately the frequency of an external rhythmic signal while dancing, than when they perform the same movement but as a form of cyclical tasks. This difference is likely not due to the conditions with a simple repetitive tone or light, where the percentage of correct frequency of motion is rather high, but it is likely due to the complex content of music, see figure 3. This complexity in the rhythmic content allows for more articulated pattern of behavior (in accordance with the results of [3]). Monotone rhythmic signals lead people to keep the correct rhythm despite the different tasks, whereas music leads them to perform movements at significantly lower mean frequencies. Moreover, the frequency of movements is less dependent to the actual pace of the music. This leads to the conclusion that participants did not interpret dancing as a cyclical task, but performed more movements of another frequency than the instructed one. These findings can be due to the fact that in dancing not every beat of a bar is interpreted in the same manner. The lower frequency of movement is probably a requirement of dancing.

While performing cyclical movements between two targets, people generally tend to increased timeshifts than in dancing, they did not move in total accordance with the rhythmic signal. It is possible, that these findings are influenced by the lower frequency of the movements, which gives more time to prepare the turning points in the correct time. Contrasting this, timeshift was higher in slow paces. Therefore, in our opinion it is more persuasive, that because dancing per definition strongly correlates with correct timing patterns, it is easier to follow the beat here (see hypothesis 1). This importance of time in a dancing scenario obviously does not weaken the position accuracy, as there is no significant difference between the tasks in this measure.

The amount of jerk in the movement performed while dancing appears to be significantly higher during dance than cyclical rhythmic motion. This result disconfirms the intuitive idea that dancing movements should necessary be smoother and avoid jerk. Most likely, dancing and moving cyclically do not share the same type of characteristics, and dancing has a more complex articulation of movements due to the required expressiveness of dance. A more complex analysis of the performed trajectories is however required in order to pinpoint the characteristics of this difference. Jerk is significantly higher in LED compared to the other modalities. We expected music to produce lower jerk. This might be interpreted as follows: moving with low jerk is thought to lead to smoother and more efficient movements, but in dancing and with music efficiency and to execute the smoothest way between to points might not be the focus.

Interestingly, the difference found between the visual modality and music 1, extends the result of [9] by indicating that not only repetitive tones but also music can be more effective in performing rhythmic movements. This result is therefore somehow inconsistent when compared with [3]. We suggested that in music more information about timing patterns is given than in the other conditions (hypothesis 2) and therefore in music we expected lower timeshift. We could not find confirmation of this hypothesis. Instead the position error is significantly higher in the LED condition. This could be due to the fact that in here the information about rhythm as well as information about position has to be processed by the same modality. The expected interaction between music and dancing can not be found, so dancing movements seem to be independent of the signal modality inducing the rhythm.

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 that could create a realistic haptic feedback. Although some important characteristics of dancing have been identified in this work, we intend to continue the investigation by analyzing the interaction of two partners while performing a dance movement in the same constrained way. Hopefully, this condition will offer more insight into the role of the tactile and haptic modalities thanks to the interaction between the partners.

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