On the Parametrization of Clapping

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Abstract. For a Reactive Virtual Trainer(RVT), subtle timing and lifelikeness of motion is of primary importance. To allow for reactivity, movement adaptation, like a change of tempo, is necessary. In this paper we investigate the relation between movement tempo, its synchronization to verbal counting, time distribution, amplitude, and left-right symmetry of a clapping movement. We analyze motion capture data of two subjects performing a clapping exercise, both freely and timed by a metronome.

Our findings are compared to results from existing gesture research and existing biomechanical models. We found that, for our subjects, verbal counting adheres to the phonological synchrony rule. A linear relationship between the movement path length and the tempo was found. The symmetry between the left and the right hand can be described by the biomechanical model of two coupled oscillators.

1 Introduction

Recently we have been interested in creating embodied conversational agents (ECAs) [5] with believable expressive verbal and nonverbal behavior. One of the applications is the RVT: an ECA in the role of a real physiotherapist, capable of 'acting out' the exercise sequences the user is supposed to do. This virtual trainer is reactive: she perceives the performance of the user, and adapts her reactions accordingly. The reaction often involves change of tempo of the exercises to be performed – see [14] for more details. The RVT – similarly to real trainers – accompanies some of the exercises with counting, to emphasize the required tempo. In this paper we address the issue of change of tempo of rhythmic motion, particularly exercises involving the movement of the arms and hands, like clapping. Our goal is to find the consequences of a change of the tempo on other characteristics of the motion. We seek answers for questions like: What is the effect of tempo change on the timing schedule of the claps? Does the amplitude change too? Does the motion path depend on tempo? What are the individual differences? How is rhythmic counting synchronized with the motion? These questions are essential in order to be able to generate (physiotherapy) exercises, where subtle timing and lifelikeness of the motion is of primary importance. We want to be sure that the user mimics the motion of the RVT to the detail, otherwise it may not achieve the envisioned positive effect, or may be even harmful. The context of such rhythmic arm motions differs substantially from

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communicative gestures accompanying casual speech. So it is interesting to compare our findings on synchronization to what is known about synchronization of speech-accompanying gestures, in general.

Our methodology is to analyze motion captured data and eventually, speech of different real people performing exercises. In this paper we give an account on our first investigation concerning clapping, a relatively simple repetitive exercise. We discuss the subtle characteristics and synchronization and timing strategies discovered in clapping. We expect that the established methodology can be used for studying other rhythmic hand motions. Moreover, we hypothesize that some of the findings on synchrony and scheduling will be valid not only for clapping, but also for other rhythmic hand motions like pulling the arms. Ultimately, we intend to use the findings based on real people's motion and motion adaptation to generate similar behavior for the RVT in a parameterized way.

In this paper we report in depth on the first stage of our ongoing work on the analysis of data gained from two subjects. Based on the findings, we plan to gather further data and perform dedicated comparative statistical analysis of the clapping of subjects of different gender and body characteristics.

1.1 Related Work

Rhythmic limb motion is studied in biomechanics [7,8,9,10,15]. While biomechanical research is typically interested in gaining deep knowledge about a single movement characteristic, we aim to obtain insight on a wider range of characteristics on an abstraction level suitable to be used as control parameters in motion generation. Biomechanical research often limits the freedom of movement to a single joint and a single characteristic of this joint is tested extensively. We do our measurements in an environment that is un-obtrusive, and allows free, natural movements. Where data from biomechanical research is already available, we relate it to our experiment.

In human motion, there are many correlations between joint actions [13]. Statistical methods [6] and machine learning [4] have been employed to find independent parameters in human motion data. These parameters can then be used to control an animation. However, the movement parameters learned in such approaches are not very intuitive to use and are highly depended on the training data. For example, [4] reports having a parameter that sets both the speed *and* the global pose.

Our approach is similar to that in [11], in which arm animations are generated using biomechanical rules of thumb, in the domain of speech-accompanying gestures. We plan to extend that work by making animations that involve the whole body, introducing movement variability (see 5.2) and parameterization.

2 The Research Issues

2.1 Synchronization of Clap and Speech

Inspired by the movement phases identified in gestures [12], we decompose a single clap into four phases (Fig. 1). The hands can be held in their starting

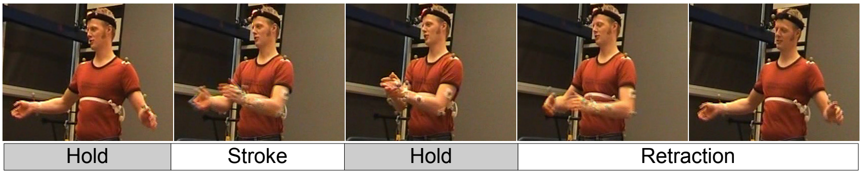

Fig. 1. Phases during a single clap

position in an *pre-stroke hold* phase. During the *stroke* phase, the hands move together. Note that, unlike the stroke phase in gestures, the stroke phase in repeated clapping does not express meaning. The hands can then be held together in an optional *post-stroke hold* phase. In the *retraction* phase, the hands move back to their initial positions.

Question 1. Does the phonological synchrony rule [12] for gestures also hold for the clapping exercise?

The phonological synchrony rule states that the moment of peak gesture effort (in the stroke phase) of a gesture precedes or ends at the phonological peak syllable of the speech. For our clapping exercise, this means that the clap moment, at which the hands touch, should precede or coincide with the phonological peak of a verbal count.

2.2 Time Distribution between Clapping Phases

When one claps slower, there is a longer time to be spent on a single clap. This can be used by simply linearly time-warping the normal clap. However, by observing people it became apparent that more complex strategies are used for the time distribution itself, and that the tempo change may have effect on the amount of motion performed. For instance, in a low tempo the hands may be kept still in a hold phase and the claps may be wider. The following questions address the possibilities.

Question 2. Are slow claps larger in amplitude, and fast ones smaller?

Question 3. How does the tempo change effect the distribution of the duration of the different phases of a clap?

2.3 Body Involvement

Involvement of the whole body is crucial to make an animation believable [1]. We want to know which body parts are involved in the clapping motion. These body parts could contribute to clapping itself, or are additional movements. In the latter case some, aspects of it could still be influenced by the clapping motion, comparable to how the tempo of breathing can be influenced by the tempo of a running motion [2].

Question 4. Which body parts are involved in clapping motion?

Question 5. How does body part involvement relate to tempo?

2.4 Symmetry

Rhythmic moving limbs have been modeled as self-oscillating systems [7,9,10]. They have their own preferred oscillating frequency, or eigenfrequency ω. Inter limb coordination patterns have been modeled as oscillator interaction through a coupled medium [8]. The oscillator travels a closed orbit in a coordinate system defined by its position (x) and velocity (v) [7]. x is the normalization of angle $\widehat{x}$ between the hand-shoulder vector and the right-left shoulder vector (Fig. 2). v is the normalized angular velocity. The location of the oscillator in its cycle is represented as a phase angle θ (See Fig. 3). The coordination of two oscillators

Fig. 2. Angle $\widehat{x}$ between the shoulder-shoulder vector and shoulder-hand vector during the clap

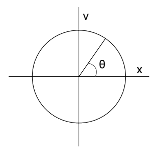

Fig. 3. Determining phase angle θ

is captured by the relative phase angle $\phi = \theta_{left} - \theta_{right}$. If the two oscillators are perfectly in phase, then $\phi = 0$. If they are perfectly in anti-phase, then $\phi = \pi$. Clapping is an in-phase movement. The stability of this in-phase behavior depends on the mass imbalance between limbs and the clapping frequency [7,15].

Question 6. Do the deviation of ϕ from 0 and the standard deviation of ϕ increase with an increase of the clapping tempo?

In an in-phase finger tapping task, it has been shown that right-handed individuals lead the tapping with their right finger [15]. However, such asymmetry often disappears when the task is constrained to a metronome.

Question 7. Do right handed subjects show a negative mean ϕ when clapping freely?

Question 8. Is the mean ϕ closer to 0 when clapping driven by metronome?

3 Setup of the Experiments

Two subjects (both male, right handed, and Dutch, age 25 and 24) were first asked to clap and to count from 21 to 30 in Dutch while clapping. We choose the words 21-30 rather than 1-10 because they consist of multiple syllables, allowing our subjects to choose a syllable to align their clap to. In Dutch, the words 21-30 have all have their phonological peak at the first syllable. In the remaining part of the paper we will call this the 'free clapping'. Then, the subjects were asked to clap to the beat of a metronome and to count while clapping. In the remaining part of the article, we will call this 'metronome-driven clapping'. The metronome is set at 30, 50, 70, 90, 110, 150, 180, 210 and 240 beats per minute. The subject had to clap twelve times at each tempo, after which the tempo was increased. The subjects were told that, if necessary, they could skip the first two metronome ticks to adjust to the new tempo. In our further analysis, we ignore motion data on clapping at those two ticks.

Motion capture is a technology which allows us to gain detailed information about the kinematic characteristics of the motion of a person, by tracking position of certain marked points of the body. We used a Vicon 460 [1] optical motion capture system with 6 cameras, recording at 120 fps. We placed the markers as indicated by the CMU marker placement guide. [2] However, to prevent occlusion between markers on the hands and those on the upper body, all markers on the front of the upper body were omitted. Thus, movement information on the torso is obtained only from the markers placed on the back. Also, we omitted the markers on the heel, ankle, and toes. Motion was recorded using 32 markers in total in the first test: four markers were placed on the head, seven on each arm, one on the neck, one on the right shoulder blade, one on the back, three on the hips and four on each leg. To save time and because we did not expect clapping to effect leg movement, in the second test, the markers on the legs were omitted. The sessions were recorded on video to gain information about the timing of speech.

4 Results

4.1 The Shape of the Movement Path

Figure 4 shows the movement path of the left and the right hand at 70 and 90 bpm for subject 1. The movement path for subject 2 looks very similar. Movement is not confined to a 2D plane, but the hands seem to move over a banana-shaped surface. The movement path is less curved as the tempo increases and the amplitude decreases. This is also observed in gestures [11].

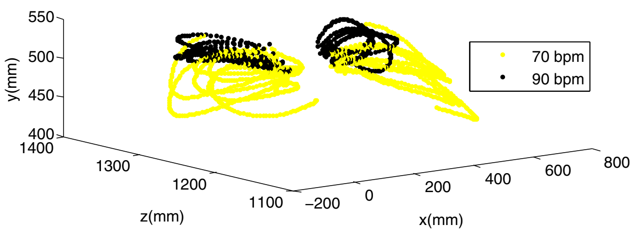

Fig. 4. Movement path of left and right hand at different speeds

[1] www.vicon.com/

[2] www.etc.cmu.edu/projects/mastermotion/Documents/markerPlacementGuide.doc

4.2 Synchronization of Clap and Speech

Both subjects in the pilot study counted after the clap moment during both free clapping and metronome-driven clapping. Thus for our subjects, the phonological synchrony rule was valid.

The free clap was performed at a consistent tempo very close to 60 bpm (with an average single clap duration of 1.007 s for subject 1 and 1.011 s for subject 2) by both our subjects. Because saying 21, 22, etc. takes about 1 second, it is likely that during this task, the timing of clapping became guided by that of the speech.

4.3 Time Distribution between Clapping Phases

Subject 1 kept moving his hands while clapping at all speeds. No hold phases were observed. Subject 2 used a pre-stroke hold phase at 30bpm and kept his hands moving constantly at the faster speeds.

Table 1 shows the average relative duration of the stroke phase for each of the clapping speeds and the standard deviation σ between the duration of the stroke phase of claps at the same speed. The duration of the preparation is always in between 31-39% for subject 1 and 22-34% for subject 2. No significant correlation between phase duration and tempo is found for our subjects. A correlation (significant at the 0.05 level) between σ and the metronome period was found for subject 1: σ increases with the metronome period. No such correlation was found for subject 2.

Table 1. Time distribution of the clap exercise at different speeds

Frequency	Stroke duration		σ	
(bpm)	sub. 1	sub. 2	sub. 1	sub. 2
30	34%	22%	9%	11%
50	34%	32%	3%	4%
70	36%	31%	3%	6%
90	34%	25%	2%	4%
110	37%	26%	3%	8%
150	34%	26%	3%	3%
180	31%	25%	3%	6%
210	36%	27%	1%	7%
240	36%	34%	2%	9%
Free	39%	32%	2%	5%

4.4 Amplitude

To measure amplitude, we first looked at the maximum distance between the hands. However, since the hand movement path is curved, this alone might not correctly display the amount of motion. We used the distance traveled along the movement path as another measure of amplitude in our quantitative analysis, which provided us with information on the hand's velocity profile as well.

Figure 5 shows the distance between the hands at different tempi for subject 1. Clearly, the maximum hand distance decreases, as the tempo increases. For subject 2, a similar pattern occurs. However, the hand distances during the 30 bpm clap (with the pre-stroke hold) and the 50 bpm clap were very similar. The maximum hand distance of subject 2 was smaller than that of subject 1 (see Table 2). While clapping at the same tempo for some time, the maximum hand distance seems to increase. This might indicate that the subject, once he is familiar with the clapping task, becomes able to execute it at a higher amplitude.

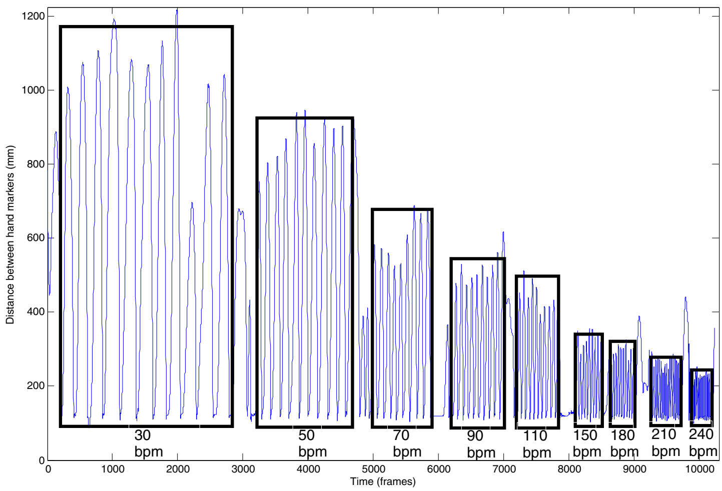

Fig. 5. Hand distance during the clapping exercise

For subject 1, free clapping has nearly the same maximum hand distance as the distance while clapping at the slowest metronome speed. This might indicate that, at least for this subject, clapping using that hand distance is 'natural' and that amplitude reduction is used as a speedup technique. For subject 2, the maximum hand distance during free clapping was much larger than that during metronome-driven clapping. However, it was still smaller than the average hand distance in subject 1's free clap.

Table 2 shows the average lengths of the path traveled through space for the hand, during the stroke (S) and retraction phase (R). The average distance traveled per minute is quite constant for the claps at the metronome. However during the free clap, the hands move at a higher speed. Possibly, this is because it is less effortful to clap freely than to exactly align the clap moment to a metronome tick. Obviously, at 30 bpm, where subject 2 makes use of the pre-stroke hold, his average clap speed is lowered. Excluding the free clap and subject 2's clap at 30 bpm, a high correlation between metronome period and movement path distance is found (Table 3, all values are significant at the 0.01 level). This

Table 2. Distance traveled along the path by the left (l) and right (r) hand during the stroke phase (S) and the retraction phase (R)

Tempo (bpm)	$R_r(mm)$ sub. 1	$R_r(mm)$ sub. 2	$S_r(mm)$ sub. 1	$S_r(mm)$ sub. 2	$R_l(mm)$ sub. 1	$R_l(mm)$ sub. 2	$S_l(mm)$ sub. 1	$S_l(mm)$ sub. 2
30	713	350	633	296	714	352	662	237
50	524	326	373	289	529	328	382	232
70	298	196	265	173	301	197	260	125
90	253	115	209	106	257	117	210	68
110	210	100	165	91	214	101	179	59
150	132	105	114	91	156	106	127	54
180	119	66	99	55	121	69	108	46
210	100	50	80	37	127	51	77	39
240	79	34	75	29	83	34	71	38
Free (60)	665	551	612	428	673	561	615	322

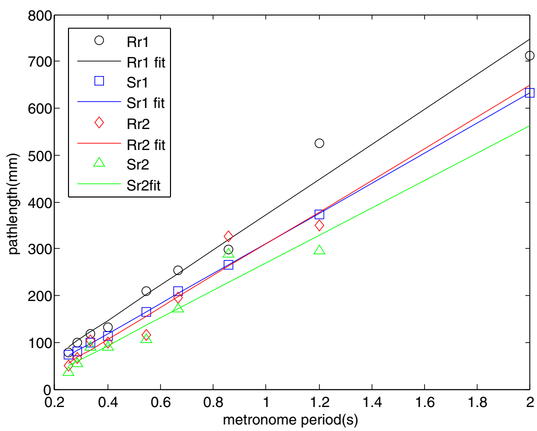

Fig. 6. Distance traveled along the path for the right hand of the subjects during stroke (S) and retraction (R)

Table 3. Correlation between metronome period and movement path distance

	Pearson sub. 1	Pearson sub. 2	Spearman's ρ sub. 1	Spearman's ρ sub. 2
S_r	1.000	0.979	1.000	0.976
S_l	0.999	0.950	1.000	1.000
R_r	0.989	0.974	1.000	0.976
R_l	0.988	0.973	0.983	0.976

indicates that there is a linear relation between metronome period and path distance:

$$pathdistance = a + b \cdot period \quad (1)$$

a and b are very similar for the left and right hand but between the two subjects and between the retraction and stroke phase, different values for a and b are found (see Fig. 6).

4.5 Involved Body Parts

For all markers, it was annotated if they were involved in the clapping motion. For both subjects, multiple body segments besides the arms were involved in the clapping motion. Movement related to clapping was found on the head, torso and at low tempi even on the thighs and knees. At higher tempi, fewer body segments were perceivably involved.

4.6 Symmetry

The relative phase angle ϕ (see 2.4) is defined as $\text{atan2}(x_{left}, v_{left}) - \text{atan2}(x_{right}, v_{right})$, in which x_i is the normalized angle $\widehat{x}$ (see Fig. 2) for limb i and v_i is the normalized angular velocity of $\widehat{x}$. x_i and v_i are normalized so that their values are in between -0.5 and 0.5. Spikes in ϕ occur when the two hand touch and the collision forces the slower hand's direction into that of the faster hand, thus flipping its angular velocity. These spikes were filtered out. Table 4 shows the mean and standard deviation of the relative phase angle of the clap at different speeds, with and without the filtering.

For both subjects, the standard deviation of ϕ increases significantly (at 0.05 level) with tempo. No relation between the mean ϕ and the tempo was found. For both subjects the mean ϕ was consistently negative when no pre-stroke hold was used, indicating that the right hand was ahead of the left hand in its cycle. For both subjects, free clapping and metronome-driven clapping at the roughly the same tempo have a very similar mean ϕ. The expected larger absolute mean ϕ in free clapping was not found. Possibly this is because the verbal count introduced another timing synchronization constraint.

Table 4. Relative phase angle at different movement speeds

Frequency (bpm)	mean (°)		σ (°)		mean (°) (filtered)		σ (°) (filtered)	
	sub. 1	sub. 2	sub. 1	sub. 2	sub. 1	sub. 2	sub. 1	sub. 2
30	10.1	12.0	73.3	26.1	-6.8	11.3	2.9	6.8
50	7.3	3.4	70.3	40.9	-7.2	-0.4	2.0	3.5
70	9.8	-6.7	85.7	47.1	-12.0	-11.0	1.9	11.4
90	9.5	4.3	83.5	55.8	-11.3	-2.9	1.5	16.4
110	7.6	-19.6	81.0	66.7	-11.5	-18.0	2.7	43.0
150	9.3	-118.1	78.4	97.6	-8.8	-105.4	3.2	144.7
180	2.9	-17.5	90.0	67.9	-3.7	-10.4	5.7	44.6
210	22.7	-40.7	115.2	87.8	-21.6	-30.1	11.4	88.2
240	4.1	-14.7	70.6	101.0	-10.4	-19.0	6.1	102.6
Free(=60)	0.8	19.3	63.1	99.4	-10.4	-10.6	2.5	7.9

5 Conclusions

5.1 Summary of the Results

1. The phonological synchrony rule was obeyed for our subjects: they both counted after clapping.

2. Our experiments have shown that clapping movement is often sped up just by making the path distance shorter, keeping the average speed and the relative timing of clapping phases the same. If this speedup strategy is used, the path distance decreases linearly with the clapping speed. The average movement speed on the path is quite constant and does not change with the metronome tempo. The value of this speed is depended on the movement phase (retraction or stroke) and on the subject (or his/her clapping style), but it does not vary much between hands.
3. A pre-stroke hold can be used as a slowdown strategy.
4. Clapping is a whole body motion. Movement related to the clap is perceived on the head, torso and even down to the knees.
5. At higher clapping speeds, fewer body parts are perceivably involved.
6. The standard deviation of the relative phase angle between the left and right hand ϕ increased with the clapping frequency. No significant increase of the mean of ϕ with the clapping frequency was observed.
7. Both our right handed subjects show the expected negative mean ϕ.
8. The mean ϕ in free clapping was similar to the mean ϕ in metronome driven clapping at the same tempo.

5.2 Discussion

The present study provided in-depth insight on different aspects of clapping. Our experiment validates several models from both biomechanics and gesture research, indicating that these models might be valid in our exercising domain. We plan to gain more information on the clapping motion by further analysis of our clapping data and by capturing new subjects.

The timing of the free clap (almost exactly 60bpm) suggests that, by asking our subjects to count while clapping in the free clap, we probably introduced speech driven clapping behavior, rather than completely free clapping. In further experiments we plan to test timing and other differences between clapping with and without counting.

We have obtained motion capture of clapping humans that can be adapted given the models we have found. Ultimately, we want to generate clapping motion procedurally, given just a tempo and some personal characteristics. A virtual human Turing test (as suggested in [16]) can be used to test the importance of our findings for the believability of motion in a in a formal way.

Variability is a measure of the differences in a motion repeated multiple times by the same person [3]. To generate natural clapping motion, variability is crucial. If we repeat exactly the same clap twice, it looks artificial. We have found relationships between variability in symmetry and time distribution and tempo. However, we have not yet shown how and where variability effects the motion path. Looking at the movement data (see Fig. 5), we hypothize that variability can be modelled solely by adjusting the clap point and maximum extension of the hands.

Style is a measure conveying the difference in the motion of two subjects [3]. Our experiments clearly show motion differences between the subjects. We would like to find out which movement characteristics are caused by personality traits (for example, introvert vs. extrovert) or specific body properties (for example, right-handed vs. left-handed). Movement data of far more subjects is needed to find significant relations between movement characteristics and style.

Movement of joints other than our arms is in principle not necesary for clapping. However, the effect of the clapping movement was seen throughout the body. We would like to know if this movement is caused just by clapping, or if clapping somehow effects movement that is already there. For example: does the clapping itself influency balance and thus induce balance changing behavior, or does it merely change the tempo of balancing behavior that is already there? In [6] and [13] movement on new joints was generated from animation pieces in a mocap database, given only a motion 'sketch' on some joints. Inspired by this work, we plan to investigate if we can generate believable movement on other body parts, given just the movement on the arms.

So far we have not looked at the *transition* from one clapping tempo to another. In the recorded motion capture data the tempo changes were large and took effect immidiately. Our subjects could not adapt to this changes immidiatly and often stopped clapping to listen to the new tempo and get used to it. We expect tempo changes in the RVT to be smaller and smoother. We plan to analyze tempo transition movement by doing another metronome driven clapping experiment, in which the metrome speed increases in smaller steps.

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