SYNCHRONIZATION OF JUMPING HUMANS WITH RHYTHMIC AUDIBLE STIMULUS

A. MOTIVATIONS

How do humans (age ~20 y.o.) synchronize their jumps with a rhythmic audible stimulus?

→ How well do they perform? Comparison of the jumping frequency with respect to that of the stimulus.

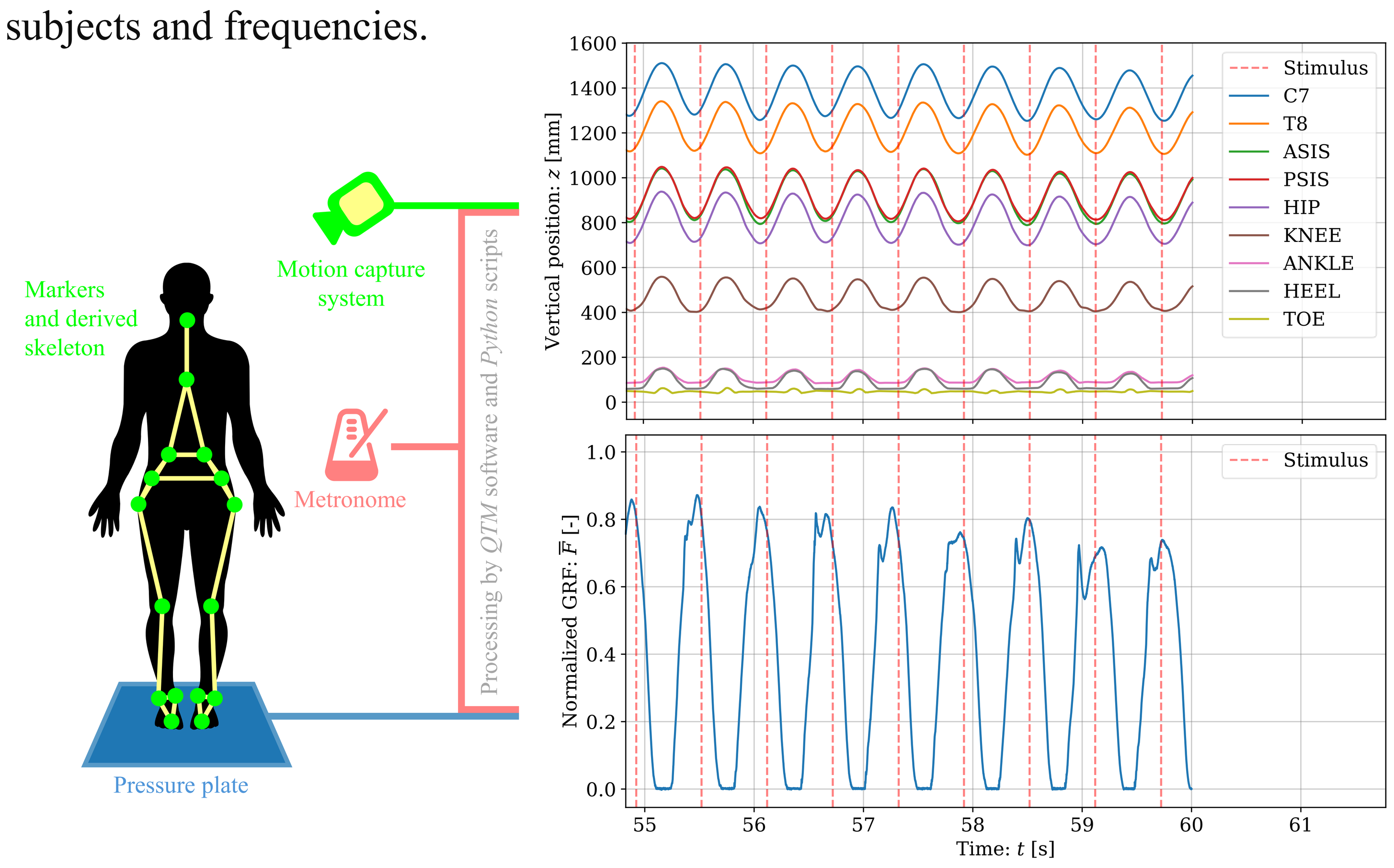
→ By which means? Analysis of the different trajectories and reaction force profiles used for jumping.

→ What about mutual synchronization? Observation of coupling of jumping frequencies for two subjects.

B. METHODOLOGY

Setup:

The subject wears motion capture markers and jumps on a force-sensing plate. Meanwhile, a metronome produces a rhythmic audible sound. The experiment is repeated for several subjects and frequencies.



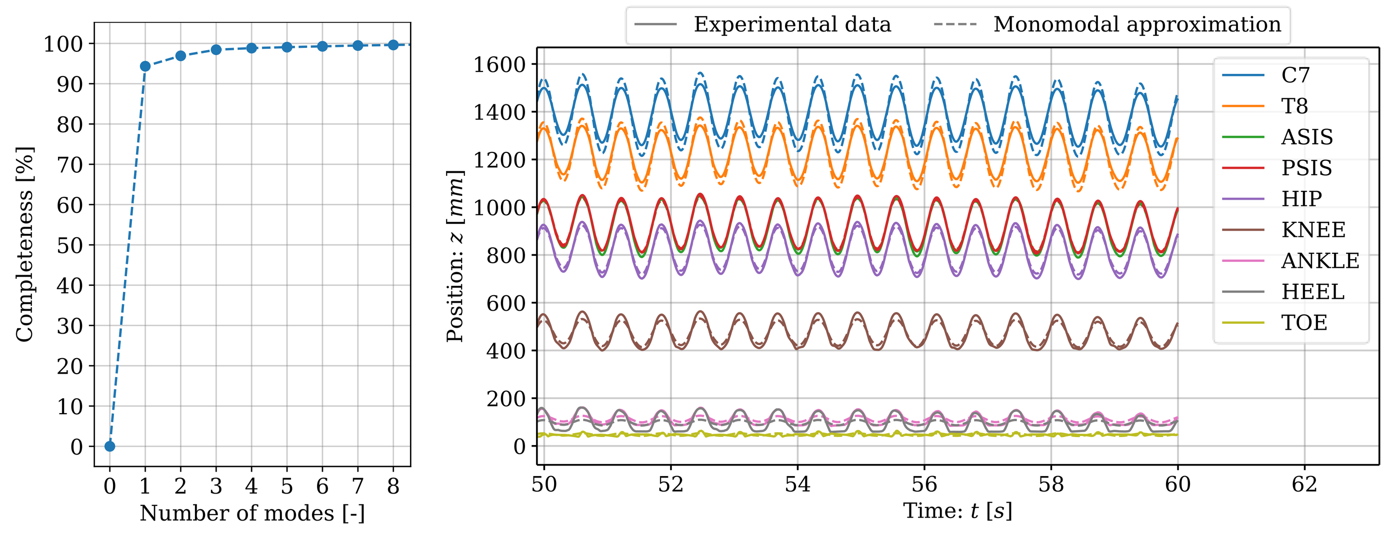
Tracking of the markers' position is performed by a motion capture system. Markers are placed on C7 vertebra, T8 vertebra, pelvis (4), hips (2), knees(2), heels (2), ankles (2), big toes (2).

The Ground Reaction Force (GRF) is sensed by pressure plates.

General data acquisition is made by the interface of the *Qualisys Track Manager (QTM)* software and post-processing is done with *Python* scripts.

Preliminary study:

Find the minimum set of relevant degrees of freedom, using a Singular Value Decomposition (SVD).



The SVD shows a ~95% accuracy only keeping the main mode. The best fitted markers for this mode are those around the pelvis, close to the centre of gravity. The movement is reconstructed by the monomodal approximation with good accuracy.

In the end, only one degree of liberty is needed for ~95% completeness.

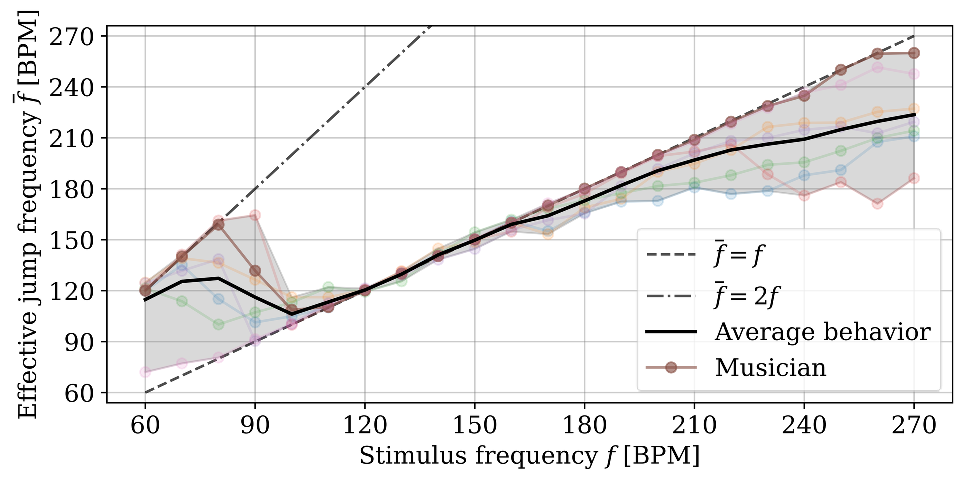
General protocol:

In the following tests, two markers are used to track the centre of gravity. The experiment takes place in different configurations, each one lasting one minute.

1. The subject jumps without an audible stimulus, at his "natural frequency".
2. The subject is asked to jump in response to an audible stimulus at different frequencies, ranging from 60 to 270 BPM with a 10 BPM increment each time.
3. Two subjects are asked to jump on two different plates, without seeing each other and without any other stimulus than the sound of the other subject's jumps.

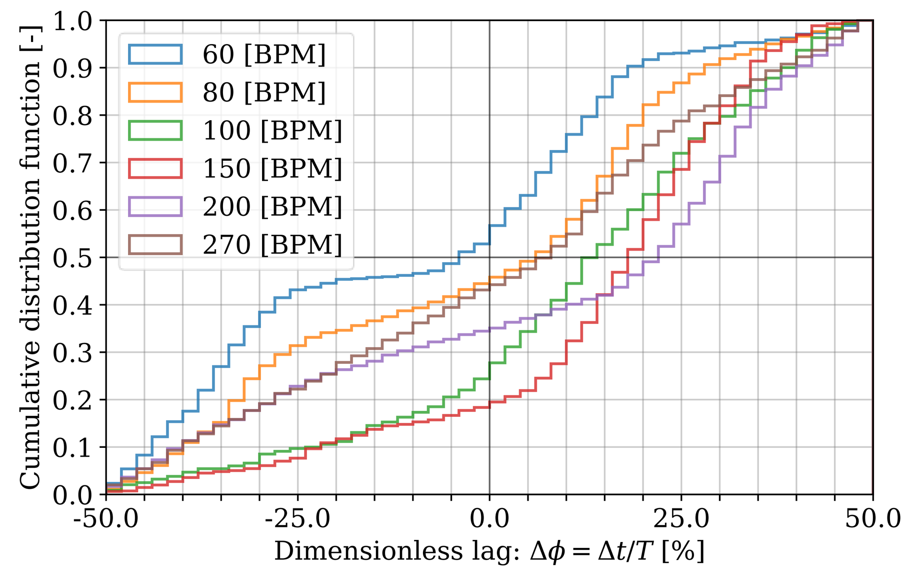
C. OBSERVATIONS

Synchronization to stimulus (frequency):



Reading the graph from right to left, the subjects seem to drop out ($f \gtrsim 180$ BPM), stick very close to the beat ($100 \lesssim f \lesssim 180$ BPM), and then progressively adopt a double-jump profile ($f \lesssim 100$ BPM). It is worth noting that the only musician of this study showed to perform very well, but this result is of course not robust.

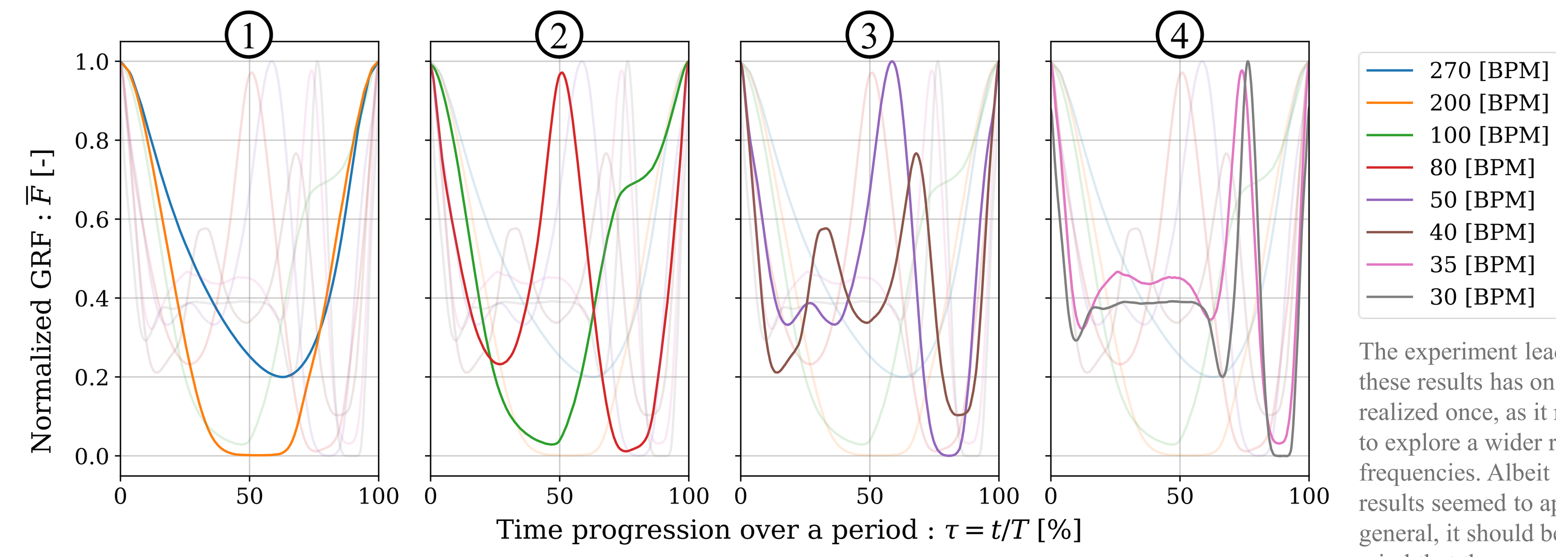
Synchronization to stimulus (phase shift):



It must be borne in mind that the phase shift is not relevant for synchronization performance since it measures the maximum GRF time, instead of the overall movement dynamics. These results are thus more indicative of the overall movement dynamics.

The dimensionless phase shift (or lag) is a measure of the time lapse between the audible stimulus and the production of the maximum GRF. For low frequencies, the double-jump is clearly visible, and then combines into one clear jump for intermediate frequencies. For higher frequencies, the jumps are timed randomly, tending towards a uniform distribution, even though the average phase shift is zero.

Jumping profile:



The experiment leading to these results has only been realized once, as it requires to explore a wider range of frequencies. Albeit those results seemed to appear in general, it should be kept in mind that these results were obtained from only one subject.

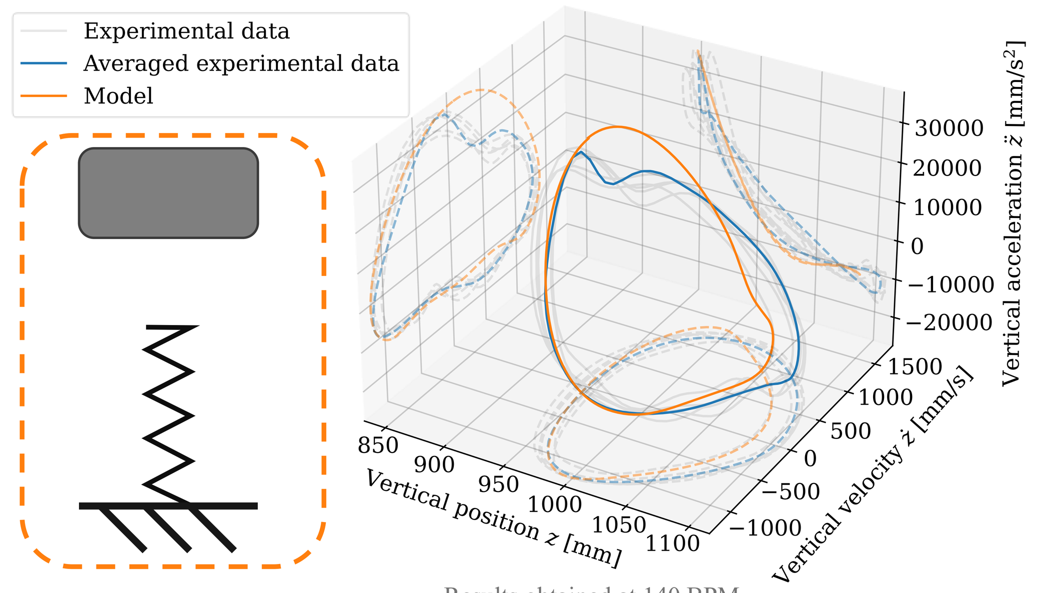
① Bobbing (270 BPM), regular jumping (200 BPM).

② Second jump appearing (100 BPM), double-jumping (80 BPM).

③ Third jump appearing (50 BPM), tiple-jumping (40 BPM).

④ Slight quadruple jump (35 BPM), pause between jumps (30 BPM).

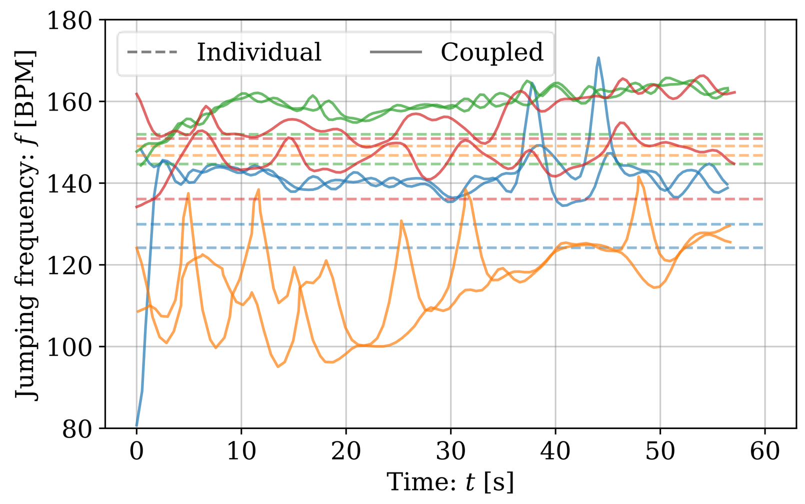
State space model:



Results obtained at 140 BPM

An attempt to model the jumping dynamics was that of a mass-spring system in which the mass can experience free fall when it is higher than the natural length of the spring. The prediction fits relatively well for such a simplistic model. Nevertheless, the physical parameters were determined in a heuristic manner.

Inter-subject synchronization:



Once the natural frequencies of two individuals are recorded, they are asked to jump synchronously, without any external stimulus than the sound of the other's jumps. When good synchronization is observed, it seems to happen quickly, in less than 5 seconds. The red curve corresponds to a voluntary asynchronization. The coupled frequencies appear unrelated to the natural frequencies.

D. CONCLUSIONS

This study lays a groundwork for future research in the field of human synchronization. It explores the question from different perspectives, showing that humans tend to drop out at too high frequencies or adapt their jumping profile at lower frequencies. The latter is studied in more detail so as to characterize this adaptation. Phase lag is also analysed statistically. A model as a spring-mass system can yield an approximatively good result but would benefit from further improvement. Finally, studying inter-subject synchronization shows no evident correlation with the natural jumping frequencies.

E. PERSPECTIVES

Enlarge population to improve robustness and derive a statistical model for large-scale simulation.
See if musicians perform especially well, as hinted by the synchronization curve.
Study the inter-subject synchronization of larger groups.
Develop a better state-space model.
Study the influence of music (at different syncope rates) instead of a beat.
Analyse lag autocorrelation of successive jumps.

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