Coordination of Groups Jumping to Popular Music Beats

Lefteris Georgiou [1], Vitomir Racic[2], James M. W. Brownjohn[3], Mark T. Elliot[4]

[1]Graduate Student, [2]Lecturer in Structural Engineering
Department of Civil and Structural Engineering, The University of Sheffield
Sir Frederick Mappin Building, Mappin Street, Sheffield S1 3JD, United Kingdom

[3]Professor of Structural Dynamic
College of Engineering, Mathematics and Physical Sciences, University of Exeter
North Park Road, Exeter EX4 4QF, United Kingdom

[4]Research Assistant- Sensory Motor Neuroscience
Department of Psychology, The University of Birmingham
Edgbaston, Birmingham, B15 2TT, United Kingdom

ABSTRACT

Prediction of coordinated dynamic loads induced by groups and crowds of people remains one of the most significant problems faced by designers of grandstands in entertaining venues, such as stadia and concert halls. Available guidance portrays humans as deterministic robot-like force generators moving at a single frequency with either perfect synchronisation or with random phases. Humans are not robots, and natural variability and imperfect synchronisation of individuals point to a random approach for crowd loading.

This research aims to tackle this challenging topic by studying, measuring and quantifying coordination between force signals measured from 15 individuals jumping to a selection of popular pop and rock songs with different dominant beats. The results show a lack of strong synchronisation pattern between individuals in a group at all given songs and rhythms. However, there is a moderate level of synchronisation at songs with predominant beats in the range 2-3 Hz.

KEYWORDS: vibration serviceability, crowd loading, synchronisation.

1 INTRODUCTION

Modern entertaining venues often include long-span open plan floors with low natural frequencies, making them prone to vertical vibration under group and crowd loading. Concert events are becoming a particularly sensitive issue as music beats help individuals to adopt a “regular” motion pattern and also serve as a common stimulus that could improve coordination (also called “synchronisation”) of the body motion of individuals in the group/crowd [1]. High levels of synchronisation at bouncing rates that resonate or nearly resonate with natural frequencies of the supporting floor may cause vibration response so large that vibration serviceability and even public safety can be jeopardised. For example, in 2003 Leeds Town Hall had to be evacuated after only 30 minutes of a rock concert as a 1000-strong crowd of fans induced vibrations so large that the floor occupied visibly cracked [2].

Prediction of the nature of coordinated dynamic loads induced by groups and crowds of people remains one of the most challenging topics in vibration engineering. In case of concert events, the popular belief is that bouncing is a good representative of dancing in a spot (i.e. within a limited space) and activity that people can effortlessly perform for a long period of time [3, 4]. For this reason, bouncing loads feature the majority of relevant design guideline [5]. However, when people get visibly excited, bouncing spontaneously turns to jumping leading to far higher dynamic load amplitudes acting on the supporting structure.

This paper is designed to study synchronisation between 15 individuals while bouncing to a range of popular pop songs and metronome beats. The aim of the study is to identify rhythms at which people coordinate their movement best, yielding the most critical group dynamic forces relevant for vibration serviceability assessment.

Section 2 describes experimental data collection while processing the measured data is elaborated in Section 3. Finally, key findings from the study are summarised in Section 4.

2 DATA COLLECTION AND ANALYSIS

Individual jumping forces generated by a group of 15 students were recorded using a full-scale instrumented grandstand available in the Department of Civil and Structural Engineering in the University of Sheffield (Figure 1). The grandstand has 3 rows with 5 seats each, as shown in Figure 2. Each seating place is instrumented by a force plate designed to measure the vertical contact forces between the feet and the structure.

The test protocol comprising 24 tests is summarised in Table 1. The tests were designed to cover a wide frequency range 1.5-4Hz of possible dominant frequencies observed in the contemporary popular (mainly pop and rock) music. At each frequency the participants were given two types of auditory cues: a steady metronome beat and three songs with a dominant beat at the selected frequency. The dominant frequencies were randomised in successive tests to avoid ‘habituation’ and adjusting their performance to increasing or decreasing beats. To minimise tiredness, a 5 minutes break was given between the tests when refreshments were provided. Each test lasted about 40 seconds as suggested in a similar study by Comer et al. [6]. The individual force time histories were sampled at 1000 Hz. An example of measured force signals is given in Figure 3.

Figure1: Experimental setup – instrumented grandstand in The University of Sheffield.

11	**12**	**13**	**14**	**15**
6	**7**	**8**	**9**	**10**
1	**2**	**3**	**4**	**5**

Figure 2: Arrangement of test subjects.

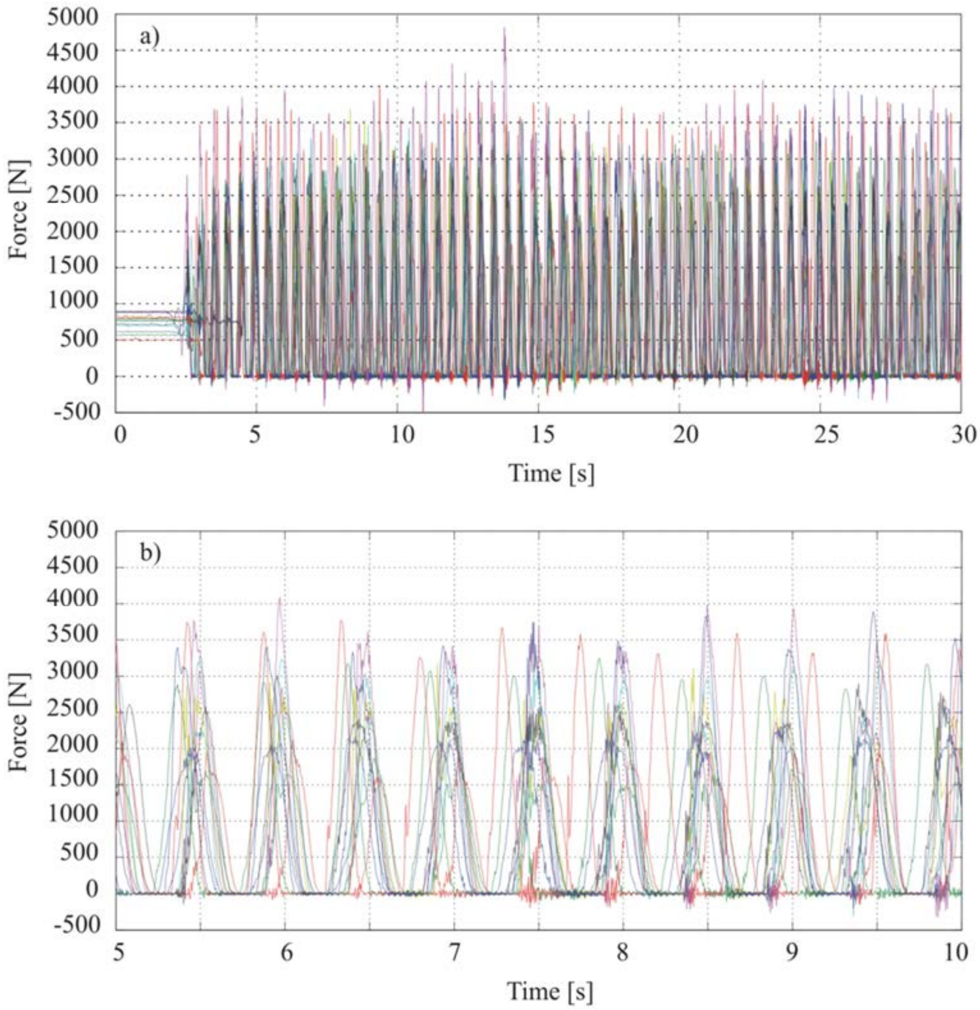

Figure 3: a) An example of recorded force-time history, b) a portion of the force record shown in a).

Table 1: Test protocol.

Test No	Frequency [Hz]	Song No/ Metronome	Test No	Frequency [Hz]	Song No/ Metronome
1	2	metronome	13	3	metronome
2	3	10	14	2.5	9
3	1.5	1	15	1.5	2
4	2.5	7	16	3.5	15
5	3.5	13	17	2.5	metronome
6	2	4	18	2	5
7	4	16	19	4	18
8	2.5	8	20	3	12
9	3	11	21	2	6
10	1.5	metronome	22	3.5	metronome
11	4	17	23	1.5	3
12	3.5	14	24	4	metronome

3 DATA ANALYSIS AND RESULTS

This section presents two approaches to quantify the level of synchronisation within the group. The first approach features the coefficient of linear correlation between the measured signals (Section 3.1), while the second approach is based on the analysis of their Fourier amplitudes (Section 3.2).

3.1 Correlation coefficients

For each of the 24 tests, the correlation coefficient ρ was calculated between the individual force-time histories. An example is illustrated in Table 2.

Table 2: An example of the correlation matrix for Song No. 04 (2.5Hz)

ρ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	0.89	0.97	0.69	0.73	0.85	0.83	0.86	0.91	0.21	0.74	-0.21	0.68	0.80	0.83
2	0.89	1	0.88	0.48	0.60	0.88	0.64	0.88	0.83	0.13	0.86	-0.40	0.77	0.92	0.92
3	0.97	0.88	1	0.68	0.72	0.83	0.82	0.82	0.95	0.23	0.71	-0.24	0.64	0.79	0.81
4	0.69	0.48	0.68	1	0.85	0.51	0.89	0.52	0.72	0.34	0.31	0.24	0.33	0.49	0.35
5	0.73	0.60	0.72	0.85	1	0.63	0.85	0.59	0.73	0.08	0.45	0.03	0.42	0.58	0.49
6	0.85	0.88	0.83	0.51	0.63	1	0.67	0.83	0.76	0.05	0.82	-0.36	0.81	0.83	0.86
7	0.83	0.64	0.82	0.89	0.85	0.67	1	0.68	0.80	0.25	0.45	0.09	0.43	0.62	0.51
8	0.86	0.88	0.82	0.52	0.59	0.83	0.68	1	0.75	0.22	0.75	-0.19	0.68	0.87	0.86
9	0.91	0.83	0.95	0.72	0.73	0.76	0.80	0.75	1	0.29	0.59	-0.22	0.52	0.76	0.71
10	0.21	0.13	0.23	0.34	0.08	0.05	0.25	0.22	0.29	1	-0.05	0.46	0.01	0.15	0.05
11	0.74	0.86	0.71	0.31	0.45	0.82	0.45	0.75	0.59	-0.05	1	-0.43	0.88	0.78	0.92
12	-0.21	-0.40	-0.24	0.24	0.03	-0.36	0.09	-0.19	-0.22	0.46	-0.43	1	-0.35	-0.34	-0.43
13	0.68	0.77	0.64	0.33	0.42	0.81	0.43	0.68	0.52	0.01	0.88	-0.35	1	0.69	0.82
14	0.80	0.92	0.79	0.49	0.58	0.83	0.62	0.87	0.76	0.15	0.78	-0.34	0.69	1	0.85
15	0.83	0.92	0.81	0.35	0.49	0.86	0.51	0.86	0.71	0.05	0.92	-0.43	0.82	0.85	1

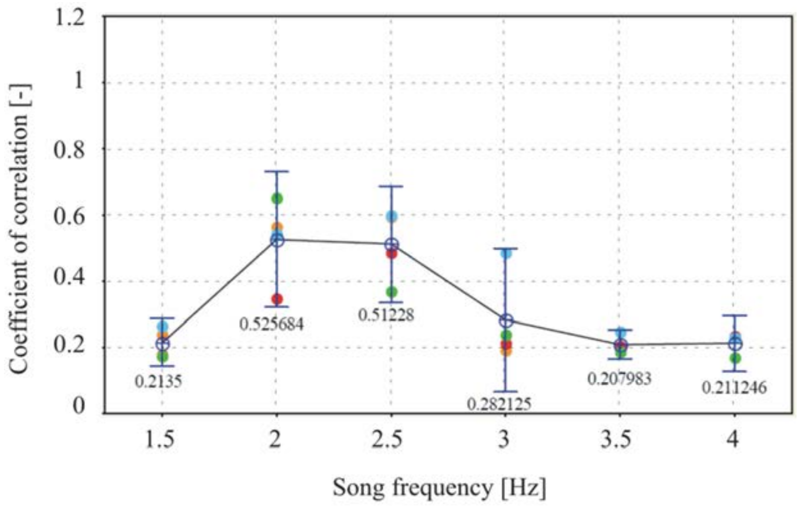

Figure 4: Summary of the group correlation coefficients extracted from the 24 tests. The black lines connect the mean values across the tests with common dominant frequency, while the whiskers represent 95% confidence intervals.

The root-mean-square (RMS) of all correlation coefficients of kind shown in Table 2 was then taken as a representative of the group correlation in each test. The results are summarised in Figure 4.

The correlation is not significant in any test (i.e. RMS<0.75). This can be interpreted as the human inability to strongly coordinate their body motion during jumping at any rate. However, the highest correlation observed for songs and metronome beats with dominant frequencies 2 and 2.5 Hz indicates mild correlation and suggests that the participants were synchronised best in this frequency range. This is in line with observations previously reported by Comer et al. [6]. Interestingly, there is no strong evidence to support the hypothesis that people follow music beats better than metronome beats. It seems that the correlation is stronger or weaker depending on how much people enjoy a particular song.

3.1 Synchronisation analysis in frequency domain

Each force record was first detrended (i.e. the mean removed) and scaled by the corresponding body weight of the individual, then their Fourier amplitude spectra were calculated. Examples of the spectra are shown in Figure. The key information extracted from each spectrum is the peak Fourier amplitude A_i, which corresponds to the dominant frequency of the force signal. They were further used to roughly estimate synchronisation factor alpha using the following equation:

$$\alpha = \frac{\mathrm{A}}{\sum_{i=1}^{15} A_i} \tag{1}$$

Here, A is the peak amplitude in the spectrum of the group force, i.e. the sum force of individual 15 force-time hisories. Values of α close to 1 indicate a good synchronisation of the group. On the other hand, values close to zero are a sign of poor synchronisation. The results across all the tests are summarised in Figure 5.

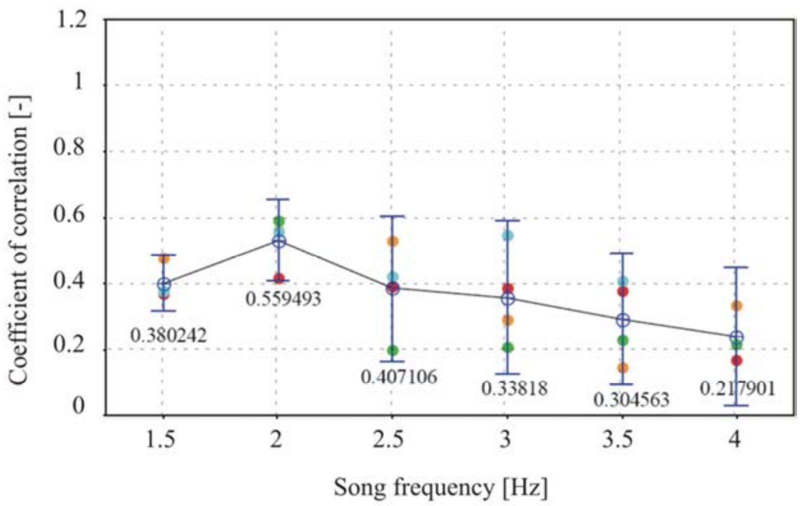

Figure 5: Summary of α-coefficients extracted from the 24 tests. The black lines connect the mean values across the tests with common dominant frequency, while the whiskers represent 95% confidence intervals.

As in the previous section, the results presented in Figure show mainly low levels of synchronisation at very fast bouncing rates. Moreover, the peak value indicates that the best synchronisation was achieved when the participants were bouncing at metronome beats and songs with dominant frequency of 2Hz. On the other hand, the mean value corresponding to 2.5 Hz is on the lower side and is very similar to the value corresponding to the low rate of 1.5 Hz.

4 SUMMARY AND CONCLUSIONS

Based on experimentally measured force-time histories generated by a group of 15 individuals bouncing to a range of pop songs and metronome beats, this study quantifies the level of synchronisation of individuals in the group using two methods. The first method features the linear correlation between the measured signals in time domain, while the second method compares contribution of the dominant Fourier amplitudes of individual force signals to the amplitude of the group force.

Both methods showed best synchronisation at moderate bouncing rates in the range 2-2.5 Hz and significantly lower levels of synchronisation at slower and faster rates. This is totally in line with results reported in similar studies in the past. A possible interpretation of the findings is that the moderate rates were the most comfortable to the majority of test subjects, thus making their bouncing motion more consistent long term. Interestingly, the results derived from the tests where songs were played were not significantly different to those derived from the tests where the metronome beats were provided. However, in feedback after the experiments the majority of test subjects agreed that the metronome beats were less stimulating that music, although the beats gave them impression that they could control their repetitive motion better.

The results presented are derived from the forces generated by a single group of students following a single set of selected pop songs and metronome beats. Testing groups of different sizes, age, professions and ethnical background while bouncing to a wider range of music genres would provide a much closer insight into synchronisation patters among groups and ultimately crowds.

ACKNOLEDGEMENTS

The authors would like to acknowledge the financial support provided by the UK Engineering and Physical Sciences Research Council (EPSRC) for grants reference EP/I029567/1 (Synchronisation in dynamic loading due to multiple pedestrians and occupants of vibration-sensitive structures) and EP/K036378/1 (Advanced measurement, modelling and utilisation of bouncing and jumping loading induced by groups and crowds). Also, the author would like to thank all test subjects for participating in the data collection.

REFERENCES

[1] Jones CA, Reynolds P, Pavic A (2011) Vibration serviceability of stadia structures subjected to crowd loads: a literature review. Journal of Sound and Vibration 330 (8), 1531-1566.

[2] Parker D (2003) Rock fans uncover town hall floor faults. New Civil Engineer, 20 November.

[3] Yao S, Wright JR, Pavic A, Reynolds P (2006) Experimental study of human-induced dynamic forces due to jumping on a perceptibly moving structure. Journal of Sound and Vibration 296 (1-2), 150-165.

[4] Sim JHH, Blakeborough A, Williams M (2008) Statistical model of crowd jumping loads. ASCE Journal of Structural Engineering 134 (12), 1852-1861.

[5] IStructE/DCLG/DCMS Working Group (2008) Dynamic performance requirements for permanent grandstands subject to crowd action: Recommendations for management, design and assessment. The Institution of Structural Engineers, The Department for Communities and Local Government and The Department for Culture Media and Sport, London, UK.

[6] Comer A, Blakeborough A, Williams MS (2010) Grandstand simulator for dynamic human-structure interaction experiments. Experimental Mechanics 50(6), 825-834.