Individual differences in walking to an auditory beat: Spontaneous and voluntary synchronization

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INTRODUCTION

• Rhythmic interventions can help patients with gait disability[1] but reveal significant individual differences in how patients respond to rhythmic cuing
• Gait is an excellent model to study spontaneous auditory-motor synchronization because it is:

Natural, automatic yet can be voluntary
Influenced by the characteristics of an external auditory stimulus (e.g tempo, regularity)[2]

Problem: No measurement paradigm exists that is sensitive to individual differences in spontaneous and voluntary synchronization to rhythmic stimulation while walking

OBJECTIVES

• Devise a method for detecting individual differences in responding to an auditory stimulus using gait
• Design a method to quantify the amount of adaptability to tempo changes
• Explain individual differences in both spontaneous and voluntary synchronization

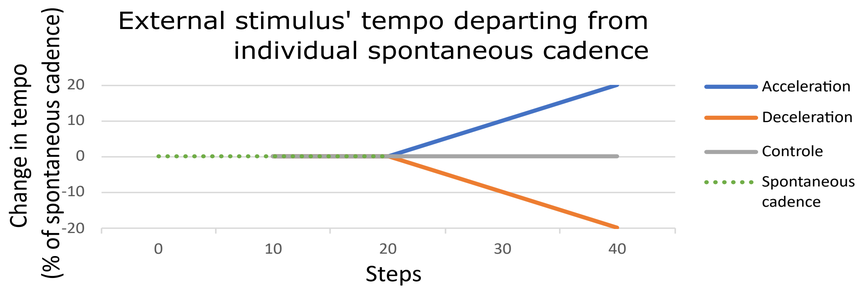
METHODS

Participants. Sixty young adults (40 females and 1 non-binary) between 18 and 40 years of age (mean = 23.95; SD = 4.1) participated in the experiment.

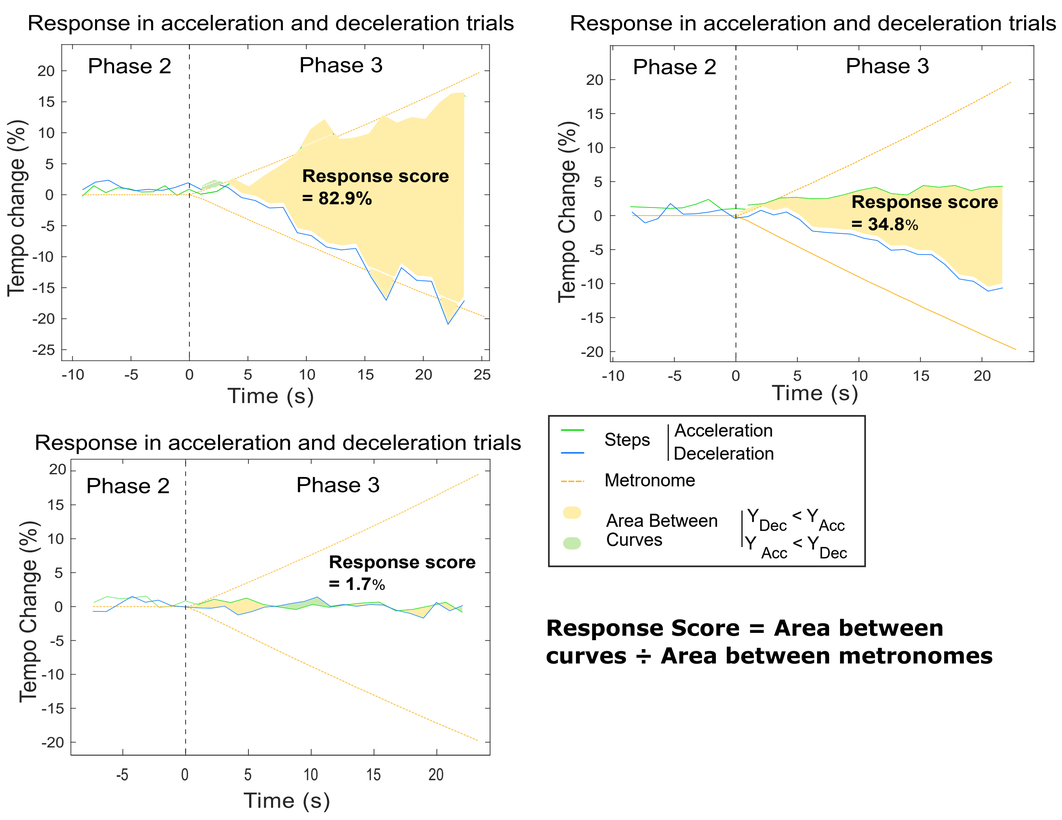
To detect steps and present stimuli tailored to participants' cadence we devised TeensyStep:
• Based on TeensyTap[3]
• Detects steps in real time via a force-sensitive resistor (FSR) connected to a custom Arduino device
• QR code for the validation paper[4]

The Ramp protocol

• Allows us to study the individual response to that tempo change with the instruction to synchronize or to walk naturally
1) A trial starts with participants walking at their preferred cadence without external stimulus
2) A metronome starts in synchrony with the footsteps
3) The metronome progressively departs from their initial cadence



The Response Score: quantifies the magnitude of the response



Response Score = Area between curves ÷ Area between metronomes

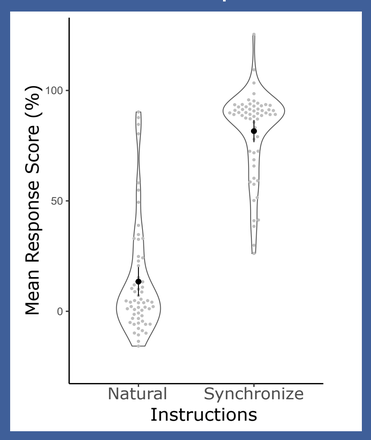
To account for individual differences reflected by the Response Score we measured:
• Rhythmic abilities using BAASTA[5,6]
• Executive functions using TAP[7] (flexibility, inhibition, working memory)

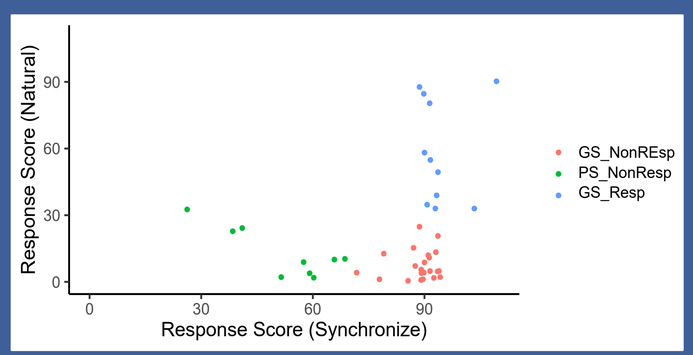
RESULTS

• Voluntary synchronization requires rhythmic abilities.
• Spontaneous synchronization correlates with low perception of tempo change and high tapping variability.

No linear relation between spontaneous and voluntary synchronization

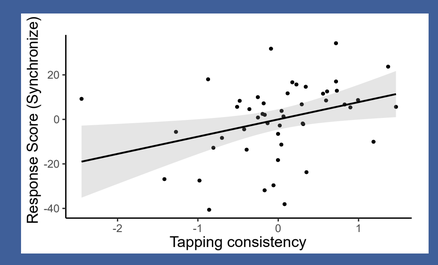
• Voluntary synchronization is necessary but not sufficient to observe spontaneous synchronization.
• 3 clusters of participants were uncovered by k-means, then grouped into "non-responders" (green and red) and "good synchronizers" (red and blue) overlapping groups in order to test the potential determinants of spontaneous and voluntary synchronization.

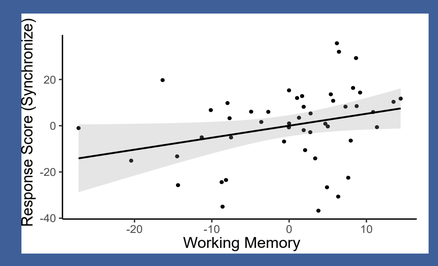




Voluntary synchronization is explained by tapping consistency and working memory

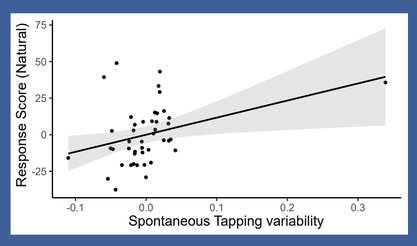
Variables	Coef.	Std. Err.	t-value	p-value	Sig.
Tapping consistency	7.75	3.30	2.35	.02	*
Beat perception	0.03	5.07	0.01	.99	
Music Training	0.50	0.45	1.11	.27	
Flexibility	0.30	0.33	0.89	.38	
Working Memory	0.52	0.27	1.95	.06	
R^2		0.40	Number of obs.		43
F-test		5.64	Prob > F		.000
Akaike crit. (AIC)		281.31			

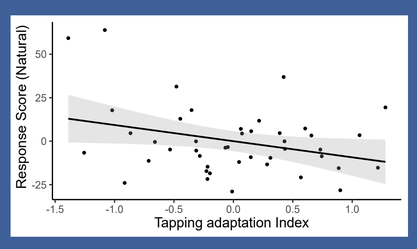


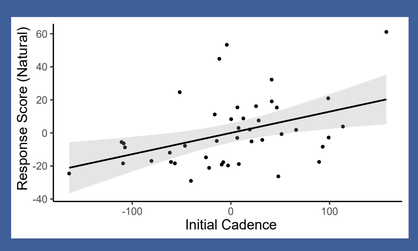


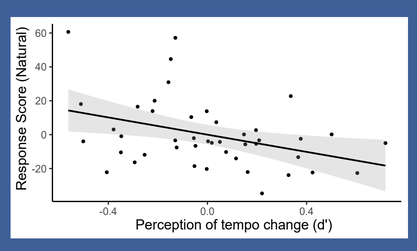
Spontaneous synchronization is explained by low scores in tapping and tempo change perception, and slow cadence

Variables	Coef.	Std. Err.	t-value	p-value	Sig.
Tapping consistency	9.19	7.52	1.22	.23	
Tapping variability	358.28	458.59	0.78	.44	
Tapping accuracy	0.23	0.24	0.95	.35	
Music training	-0.01	0.63	-0.02	0.98	
Spontaneous tapping variability	117.01	53.76	2.18	.04	*
Tempo change perception	-25.37	11.13	-2.28	.03	*
Adaptation index	-9.29	4.91	-1.89	.07	.
Variability of initial cadence	595.48	423.09	1.41	.17	
Initial cadence	0.13	0.05	2.61	.01	*
R^2		0.54	Number of obs.		34
F-test		4.45	Prob > F		.0007
Akaike crit. (AIC)		277.35			









CONCLUSION

The Ramp protocol:
• Is used to test the effect of voluntary and spontaneous individual response to the stimulus change by manipulating instructions.
• Allowed us to observe distinct response profiles, quantify the response and provides an empirical basis to explain and predict these responses.
• Allowed a better understanding of gait adaptation and can help in individualizing rhythmic interventions to improve gait disorders.

References. 1: Dalla Bella et al., (2017) Scientific Reports, 7. https://doi.org/10.1038/srep42005; 2: Leow et al., (2014) Front. Hum. Neurosci., 8. https://doi.org/10.3389/fnhum.2014.00811; 3: Van Vugt, (2020). Advances in Cognitive Psychology, 16, 302–308. https://doi.org/10.5709/acp-0304-y; 4: Zagala et al., (2024) BioRxiv, doi: https://doi.org/10.1038/s41598-024-72508-7; 5: Dalla Bella et al., (2017), Behav Res Methods, DOI: 10.3758/s13428-016-0773-6; 6: Dalla Bella et al., (2024), Behav Res Methods, DOI: 10.3758/s13428-024-02363-x; 7: Zimmermann & Fimm, (2002) https://www.psytest.net/en/test-batteries/tap/objective