Frequency tuning in human motion in variable gravity

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Context

Frequency or resonance tuning is the tendency of mechanical systems to oscillate at their preferred frequency. This property of passive systems is observable with zero or close to zero lag. The musculoskeletal apparatus makes no exception: the central nervous system exploits resonance tuning to optimize voluntary actions [1]. It is unknown how volitional control interacts with frequency tuning immediately after a change in the environment. In this study, we explore two timescales for frequency tuning during transitions between different gravitoinertial contexts.

In a simple pendulum, only two parameters dictate the entire motion: the length L of the pendulum arm, and the local acceleration g felt by the pendulum; and we find that the period of motion is given by $T \sim \sqrt{L/g}$. Nonetheless, for humans performing that type of motion one finds itself constrained in two ways:

- Musculoskeletically: one's bones, joints and muscles, mere physical objects, are drawn to a resonant frequency.
- Neurologically: the central nervous system, whose most basic function is prediction, plans motion and incorporates sensory feedback in real time.

In this experiment, 6 participants were subjected to two centrifugation sessions in which they experienced gravity profiles from 1 to 3 g, by steps of 0.5 g and back down to 1 g (Figure 1). During transitions between different gravitoinertial environments, participants performed free-paced harmonic motion with their forearm. At which timescale does each constraint dominate?

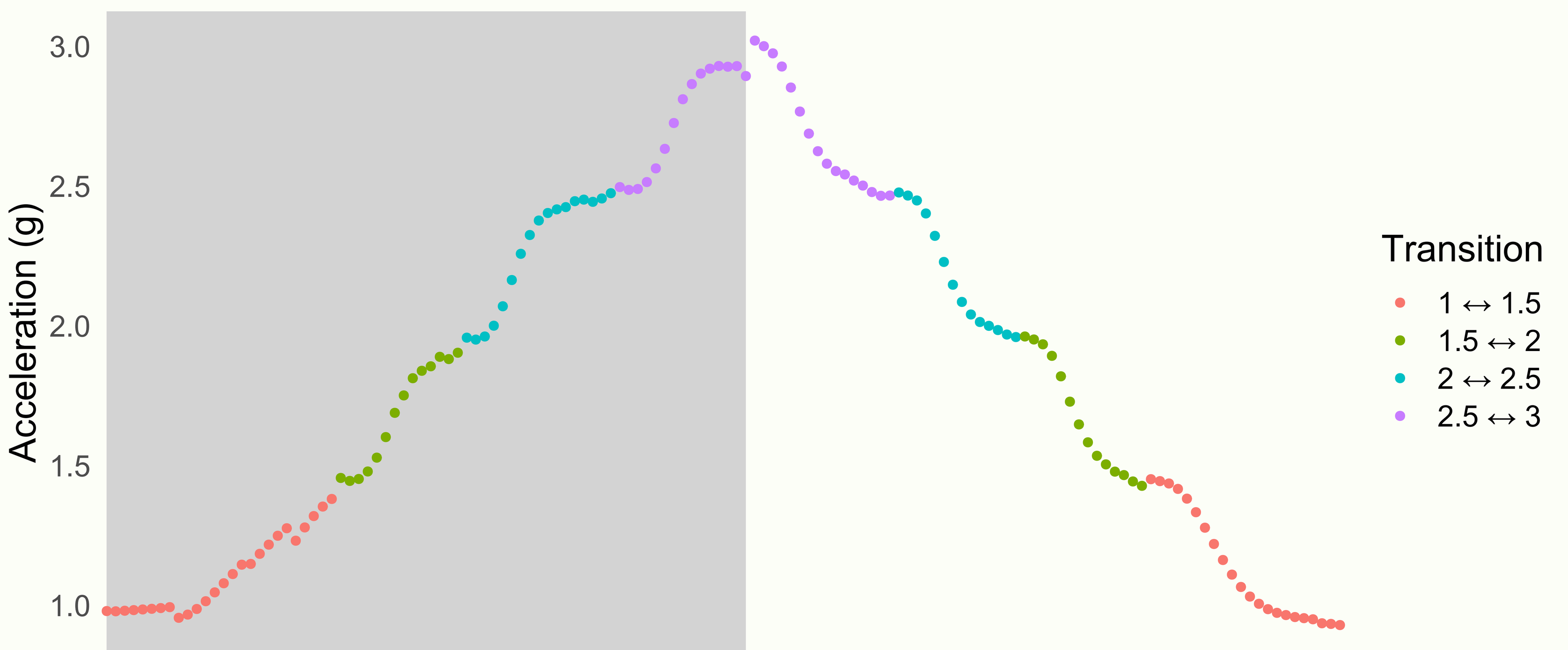

Figure 1: Acceleration profile during a centrifugation session. (Grey background denotes ascending phase.) More info in [2].

Results

We first explore the long timescale, by averaging periods over the entire transition (Figure 2). We find that our results align with basic frequency tuning principles: as the acceleration increases, the period decreases. This indicates that, for long timescale, musculoskeletal constraints dominates: the body can be modeled as a mere physical object.

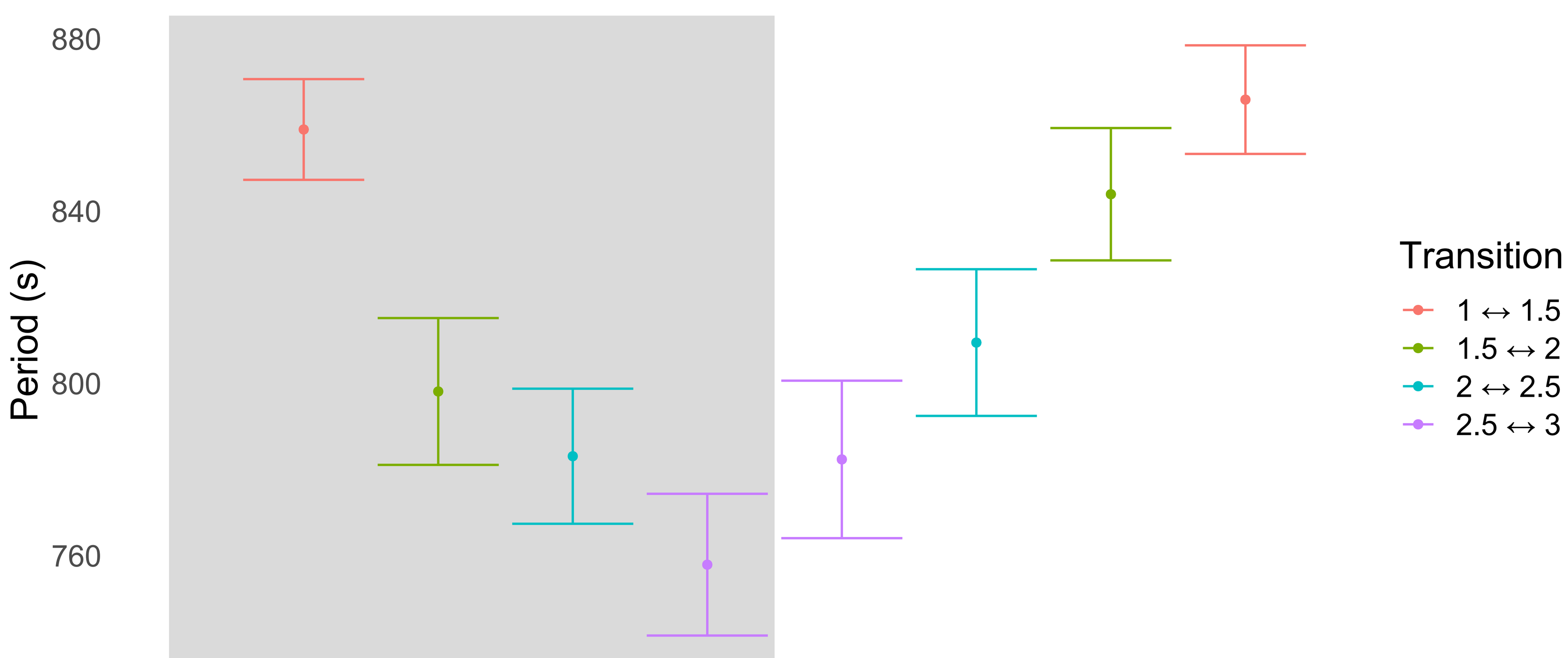

Figure 2: Period average during a transition, averaged over participants.

For short timescale the pattern continues in the ascending phase: periods decrease as the acceleration increases. Surprisingly, the opposite happens in the descending phase: as the acceleration decreases so does the period. This violates frequency tuning principles, indicating that more cognitive processes are involved at this scale.

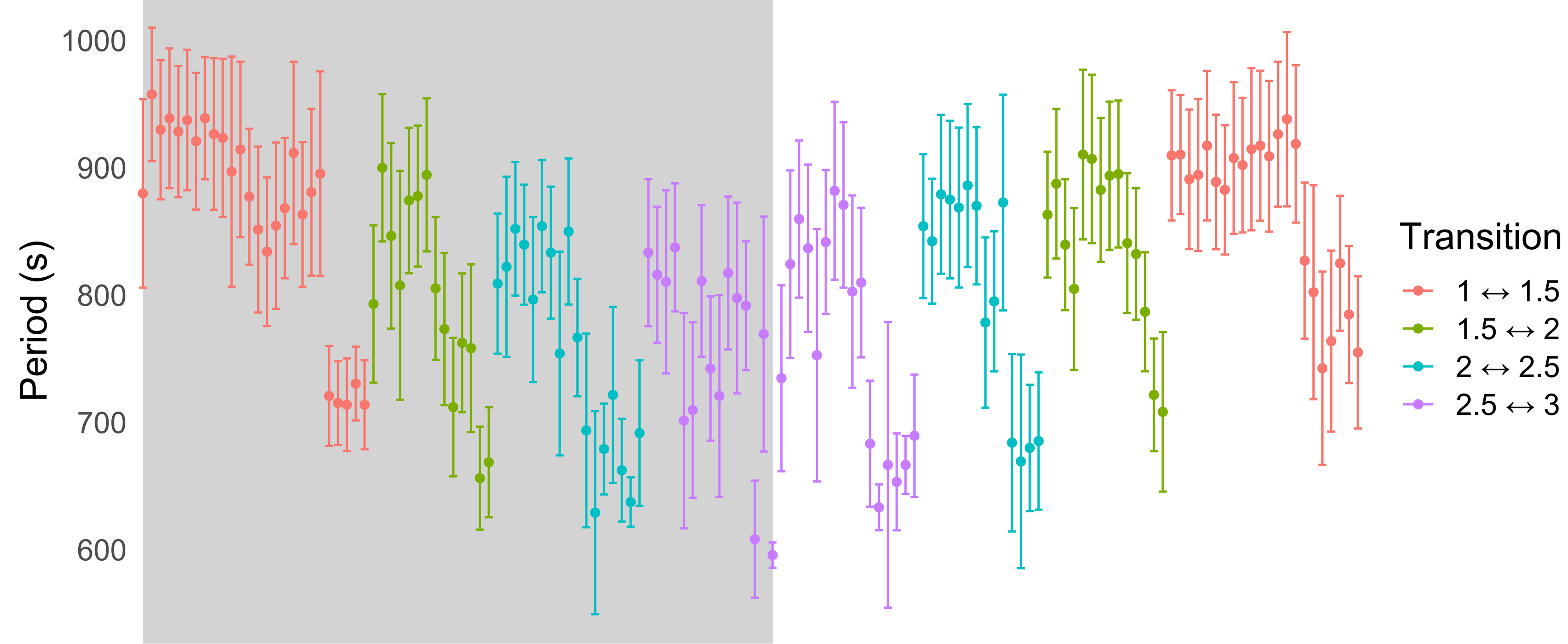

Figure 3: Period by cycle of motion averaged over participants.

Discussion

Gravity is naturally incorporated by the central nervous system, as is shown in asymmetric acceleration profiles in up-down motion, i.e. with or against gravity [3], however this only holds for gravitoinertial environments of 1 g, i.e. life on Earth.

In a new unfamiliar environment, the central nervous system cannot predict optimal motor strategies. This results in neurological constraints dominating the short timescale. Indeed, while the period should change immediately after a change of acceleration, it first plateaus for a few cycle of motion (Figure 3), seemingly locked. During this part of the transition, the central nervous system has to first incorporate sensory feedback to plan new motor strategies. As it does so, it can use frequency tuning to approach a new optimal regime.

The apparent lack of frequency tuning in the short timescale during the descending phase is most likely due to stress, fatigue and learning effects.

References

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[3] Papaxanthis C., Pozzo T. & Stapley P. «Effects of movement direction upon kinematic characteristics of vertical arm pointing movements in man» Neuroscience Letters, **253:2**, 103-106 (1998).

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