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A 5-Minute Rest Period Weakens the Phenomenon of History Dependence of Freely Chosen Pedalling Cadence and Entails a Borderland Observation

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Abstract

Background: It was recently reported that the freely chosen cadence at the end of a bout of pedalling depended on relatively high and low preset cadences applied at the beginning of the bout. This was denoted as a phenomenon of motor behavioural history dependence. **Objective:** The present study aimed at expanding that recent finding by testing whether the described history dependence occurred if 5-min rest was incorporated between the initial pedalling at preset cadence and the final pedalling at freely chosen cadence. **Methods:** Twenty-six participants performed three separate sequences of submaximal ergometer pedalling. In sequence A, pedalling at 50 rpm was followed by 5-min rest and pedalling at freely chosen cadence. In sequence B, pedalling at 90 rpm was followed by 5-min rest and pedalling at freely chosen cadence. In sequence C (denoted reference), the cadence was freely chosen throughout all pedalling. Behavioural (cadence), biomechanical (tangential pedal force), and physiological (heart rate) responses were measured. **Results:** Initial pedalling at 90 rpm caused the subsequent freely chosen cadence (74.5 ± 3.3 rpm) to be about 6% higher ($p = 0.001$) than the reference freely chosen cadence at the end of sequence C (70.8 ± 3.2 rpm). A similar difference did not occur between sequences A and C. **Conclusions:** These divergent findings, combined with previous reports of clear history dependence in pedalling sequences (performed similarly to here, only without incorporated rest periods), overall suggest that the present observations reflected a borderland of motor behavioural history dependence. Further, the 5-min incorporated rest apparently weakened the history dependence phenomenon.

Keywords

Cycling, Motor Behaviour, Motor Control, Pedal Rate, Preferred Pedalling Frequency, Rhythmic Movement

1. Introduction

Recently, a novel phenomenon of motor behavioural history dependence was reported (Hansen et al., 2021). The phenomenon implied that the freely chosen cadence at the end of a submaximal ergometer pedalling bout depended on the preset cadence applied at the beginning of the same bout. In more detail, it was found that initial pedalling at 50 and 90 rpm caused subsequent freely chosen cadence to be about 5% lower and higher, respectively, than the freely chosen cadence at the end of a reference bout, which was performed at freely chosen cadence throughout (Hansen et al., 2021). Recreationally active individuals constituted the participants.

The main finding described above was essentially replicated in a subsequent study performed with competitive cyclists as participants (Hansen & Stilling, 2021). The competitive cyclists were characterised by having cycled on average 4.1 times, or 9.4 h, per week during the year prior to the study. Accordingly, substantial cycling experience does not seem to influence the described history dependence phenomenon. The present study builds on and aims to extend, the knowledge that we obtained from the studies by Hansen et al. (2021) and Hansen and Stilling (2021).

Besides academic importance related to our general understanding of motor rhythmicity, the observed phenomenon has cycling-specific practical relevance. As merely a single example, cadence affects physiological and biomechanical responses (Abbiss et al., 2009) and, thereby, affects results from cycling tests, performed at submaximal intensity. Such tests are for example performed for the evaluation of the status of training, or fitness (Åstrand et al., 2003: pp. 282-284). In other words, a history-dependent freely chosen cadence can affect the outcome of a cycling test and the evaluation of the fitness condition of the tested individual.

At the same time as physiologically based motor output is known to be susceptible to history dependence (Abbott & Aubert, 1952; Hansen et al., 2015; Young et al., 1998), it is assumed that physiological responses tend to largely return to a kind of balanced rest status when an individual is allowed to recover. However, it is unknown whether a brief rest period held between initial pedalling at preset relatively high and low cadences and subsequent pedalling at freely chosen cadence will avert the freely chosen cadence from being history-dependent. Of note is that rest periods of 5 min are commonly applied in cycling studies where several consecutive bouts are performed (Brennan et al., 2019; Chavarren & Calbet, 1999; Marsh & Martin, 1998).

Therefore, the purpose of the present study was to test whether history-dependent freely chosen pedalling rhythmicity occurred in a second pedalling bout, performed at a freely chosen cadence when a 5-min rest period was incorporated between that bout and an initial bout, which was performed at preset target cadence. In the case that history dependence (as it has been reported previously) indeed was averted by the incorporated rest, it could support the interpretation that a brief rest period effectively can eliminate the described phenomenon of motor behavioural history dependence.

2. Methods

2.1. Participants

Twenty-six (18 males, 8 females) healthy and recreationally active individuals (mean ± SD: 1.78 ± 0.08 m, 79.2 ± 12.1 kg, 24 ± 2 years) participated in the study. They were typically university students. All participants had experience with cycling. Though, none of them were competitive cyclists. Twenty of the participants performed bicycling as personal transportation. Six of the participants performed cycling as exercise. The participants were carefully informed about the procedures of the study and the overall aim ("to enlarge our knowledge about control of rhythmic leg movement"). At the same time, they were kept naïve to the specific purpose of the study. The reason for this was to avoid any particular conscious control of the cadence when this was freely chosen. Written informed consent was obtained from the participants. The study conformed to the standards set by the Declaration of Helsinki and the procedures by The North Denmark Region Committee on Health Research Ethics.

2.2. Overall Design

Each participant reported to the laboratory once, for a test session of approximately 1 h duration.

During the test session, the participant performed separate sequences of submaximal ergometer pedalling at preset and freely chosen cadences, while behavioural, biomechanical, and physiological responses were measured. Sequences were performed in a counterbalanced order.

2.3. The Test Session

First, the participant's height and body mass were measured, and age was noted. Next, the participant was asked about the cycling experience. Then, the seat height of the electromagnetically braked SRM cycle ergometer (Schoberer Rad Messtechnik, Jülich, Germany) was adjusted according to "the heel method" (Bini et al., 2011). Furthermore, the ergometer's power measuring unit, as well as the Powerforce system for tangential pedal force measurements (Radlabor GmbH, Freiburg, Germany), were reset according to the manufacturer's manuals.

Next, a 6-min familiarisation bout was performed. For this, the cycle ergometer was pre-programmed to maintain a power output of 100 W. Gear 8 and "constant watt" operating mode on the SRM cycle ergometer were used. This ensures a pre-programmed power output regardless of the applied cadence. The participant started pedalling at a freely chosen cadence for 2 min followed by 1 min at a target cadence of 50 rpm, 1 min at a target cadence of 90 rpm, and finally 2 min at freely chosen cadence. For the pedalling at freely chosen cadence, the following instruction was given: "You must now pedal at a freely chosen cadence. There is no correct or incorrect cadence. Simply, pedal as you find it natural". The purpose of the familiarisation was to allow the participant to get accustomed with the cycle ergometer and the built-in latency of the computer-controlled adjustment of resistance when cadence is changed. The familiarisation bout was followed by a 10-min passive rest period.

After the rest period, three separate 12-min sequences of ergometer pedalling were performed at a pre-programmed power output of 100 W. The sequences were performed in counterbalanced order and denoted sequence A, B, and C. All three sequences were separated by 10-min passive rest periods. Sequence A consisted of 2 min of pedalling at a preset target cadence of 50 rpm followed by a 5-min rest period and 5 min pedalling at freely chosen cadence. Sequence B consisted of 2 min of pedalling at a preset target cadence of 90 rpm followed by a 5-min rest period and 5 min pedalling at freely chosen cadence. Sequence C consisted of 2 min of pedalling at freely chosen cadence followed by a 5-min rest period and 5 min pedalling at freely chosen cadence. Sequence C was considered a reference sequence for the analysis of data. Based on previous work, it was predicted that the cadence in sequence C would be about 70 rpm, as a mean value across participants (Hansen et al., 2014; Sardroodian et al., 2014). Fifty and 90 rpm at the beginning of sequences A and B were deliberately chosen to represent considerably lower and higher cadences, respectively, compared to the predicted freely chosen cadence. It applied to all sequences that when cadence was at a preset target, visual cadence feedback was given to the participant. However, when cadence was freely chosen, the participant was blinded to the cadence. Participants wore their own sports shoes during the ergometer pedalling. The pedals were mounted with toe clips. The test session is inspired by previous studies (Hansen et al., 2021; Hansen & Stilling, 2021). The major difference is that a 5-min rest period was held between the initial and the final pedalling.

2.4. Data Recording and Analysis

Data recording during pedalling in a sequence is illustrated in **Figure 1**. Cadence was recorded every 30 s during pedalling. A single value of the freely chosen cadence was calculated as a mean across the last 3 min of each sequence, for further analysis. Tangential pedal forces (forces directed perpendicular to the crank arm, with positive values in the rotation direction, see **Figure 2**) from the left and the right pedal were recorded twice during each sequence for a duration of 30 s from 1:15 (min:s) to 1:45 and again from 11:15 to 11:45. The forces were recorded at 2000 Hz using a 16-bit A/D converter, and the data acquisition Lab-

VIEW-based software IMAGO Record (part of the Powerforce system). For each 30-s recording, the Powerforce system software calculated a single mean tangential pedal force profile for one revolution (for an example, see Figure 2) for each of the two pedals. From these profiles, maximum and minimum values of the tangential pedal force, as well as the crank angles at which these values occurred, were found. Mean values of the values from the left and the right pedal were calculated for further analysis. Heart rate was determined by a Garmin Forerunner 245 (Garmin International Inc., Olathe, KS, USA) at the end of each sequence (at 11:45).

2.5. Statistical Analysis

A sample size estimation performed (https://www.biomath.info/power/prt.htm)

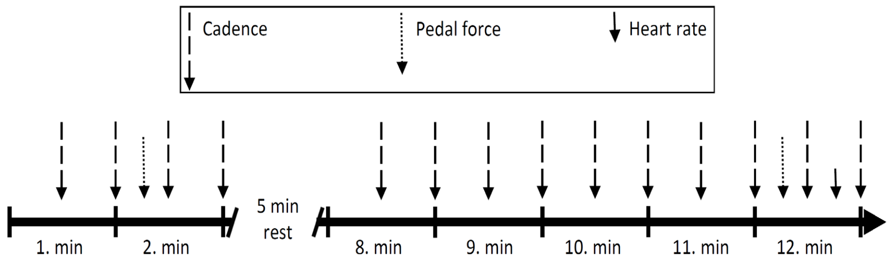

Figure 1. An overview of data collection during a single sequence of ergometer pedalling. In sequence A and B, the initial 2 min was performed at a preset target cadence of 50 rpm and 90 rpm, respectively. The rest of the sequence was performed at freely chosen cadence. In sequence C, the cadence was freely chosen throughout. A 5-min rest period was held between the initial and final pedalling.

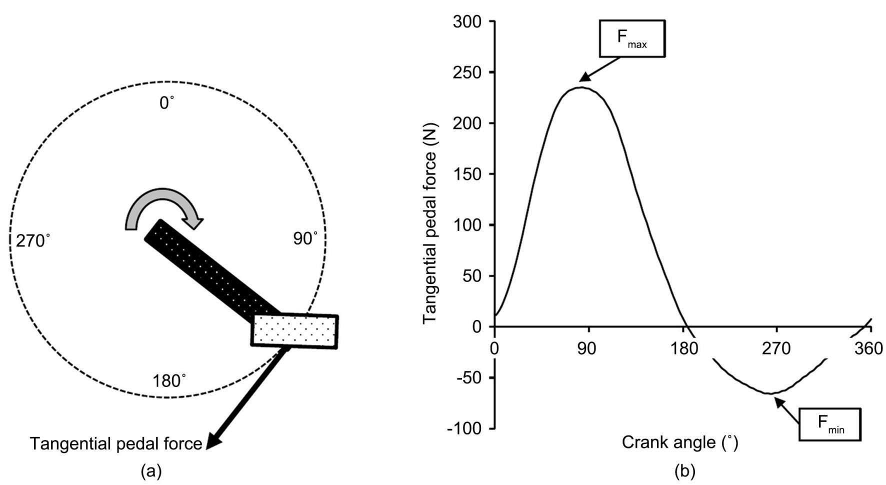

Figure 2. Panel (a) is an illustration of the direction of the tangential pedal force (perpendicular to the crank arm) for the right pedal. An illustration for the left pedal would have been mirrored. The crank cycle can be divided into three main sections. A pushing section (350˚ - 10˚), a downstroke section (10˚ - 180˚), and an upstroke section (170˚ - 350˚). Panel (b) is a data example of a tangential pedal force profile ($n = 1$). This typical example represents an average of the data recorded for the left pedal, for 30 s. The following selected key characteristics are indicated on the profile: F_{max}, maximum tangential pedal force; F_{min}, minimum tangential pedal force.

in the design phase of the study resulted in 24 individuals. This estimation was based on paired *t*-tests to be performed with an alpha value of 0.01 (set conservatively due to correction for multiple tests), an expected difference of 6 ± 8 rpm (mean ± standard deviation), and a power of 0.80. To take into account possible dropouts or missing data due to technical complications, 26 individuals were recruited. Tests for normality (Shapiro-Wilks) were performed in IBM SPSS 27.0 (SPSS Inc., Chicago, IL, USA). These tests showed that $p > 0.05$, and data were therefore considered normally distributed. Two-tailed paired Students *t*-tests were performed in Excel 2016 (Microsoft Corporation, Bellevue, WA, USA). Data are presented as mean ± SEM, unless otherwise indicated. SEM (standard error mean) was calculated as standard deviation divided by the square root of the sample size. Due to the design of the study, where data from two sequences (A and B) were systematically compared with data from sequence C (considered a reference sequence), $p < 0.025$ (i.e., 0.050/2—family-wise Bonferroni correction) was considered statistically significant in the present study.

3. Results

Unfortunately, a few data were lost due to technical complications. Therefore, the size of *n* for each kind of data is specified hereinafter.

3.1. Cadence

Cadence is depicted as a function of time in **Figure 3**, for all three performed sequences of submaximal pedalling. The freely chosen cadence during the last 3 min of sequence A was not statistically significantly different from sequence C (−2.1% ± 8.7%, mean ± SD, $p = 0.168$). For comparison, the freely chosen cadence during the last 3 min of sequence B was 5.7% ± 7.1% (mean ± SD) higher than during sequence C ($p = 0.001$). For absolute values of cadence, the reader is referred to **Table 1**.

Table 1. Selected key characteristics of the tangential pedal force profile. Data are from submaximal pedalling at a pre-programmed power output of 100 W. Freely chosen cadences at the end of the sequences (mean values across the last 3 min) are also included.

	F_{max} (N)	Crank angle at F_{max} (˚)	F_{min} (N)	Crank angle at F_{min} (˚)
Sequence A (“50 *rpm to FCC*”)				
Initially (at 50 rpm)	250 ± 5	88 ± 1	−71 ± 4	291 ± 2
Finally (at 69.2 ± 3.2 rpm)	241 ± 6	92 ± 1	−82 ± 3	277 ± 3
Sequence B (“90 *rpm to FCC*”)				
Initially (at 90 rpm)	202 ± 7	89 ± 1	−84 ± 3	268 ± 2
Finally (at 74.5 ± 3.3 rpm)[a]	237 ± 7	92 ± 1	−85 ± 3	272 ± 2
Sequence C (“*FCC throughout*”)				
Finally (at 70.8 ± 3.2 rpm)	243 ± 7	91 ± 1	−82 ± 3	276 ± 2

FCC, freely chosen cadence. [a]Different from the cadence in sequence C ($p = 0.001$). $n = 22$.

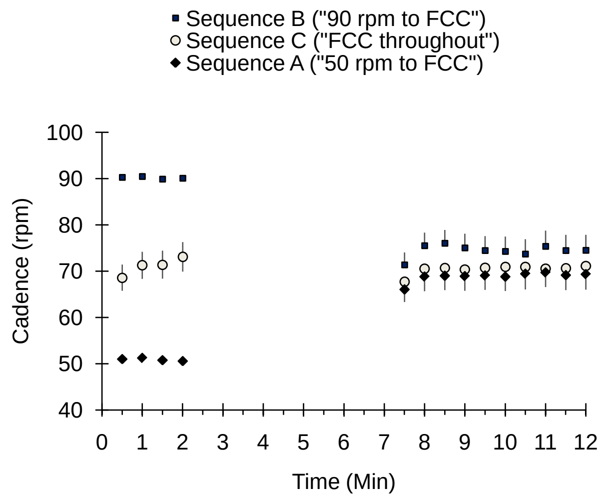

Figure 3. Cadence as a function of time during the three performed sequences of pedalling at a pre-programmed power output of 100 W. Data are mean values calculated across the group of participants. SEM-bars are only shown in one direction for sequences A and B and not at all for the final pedalling in sequence C—for the sake of clarity. For the initial pedalling in sequences A and B, the SEM-values are hidden within the data symbols. $n = 26$.

3.2. Pedal Force Profile

Key characteristics of tangential pedal force profiles are presented in **Table 1**. Statistical tests were performed to differentiate sequence A from C as well as sequence B from C, as regards final values in the sequences. However, these tests did not show statistically significant differences.

3.3. Heart Rate

The heart rate at the end of sequence A was 128.6 ± 3.3 beats·min^{-1}. This was not significantly different from the heart rate at the end of sequence C, which was 127.6 ± 3.1 beats·min^{-1} ($p = 0.336$). For comparison, the heart rate at the end of sequence B was 130.4 ± 2.9 beats·min^{-1}, which was significantly different from the heart rate at the end of sequence C ($p = 0.007$). Of note is that $n = 25$ for heart rate data.

4. Discussion

The present study showed that a 5-min rest period can weaken the phenomenon of history dependence of freely chosen pedalling cadence and thereby entail a borderland observation. In more detail, the following was observed. History dependence of freely chosen pedalling rhythmicity in a second pedalling bout, performed at freely chosen cadence, was averted when a 5-min rest period separated that second bout and an initial bout performed at a relatively low preset target cadence. In divergence with that observation, history dependence occurred when the initial pedalling was performed at a relatively high preset target cadence.

In terms of physiological mechanisms, which could possibly explain the present observations, we can only speculate. The reason is that the present study focussed on behavioural rather than neurophysiological measurements. Still, it should be acknowledged that several researchers have pointed out that analysis of motor behaviour is used to understand how the nervous system is organized and function (Goulding, 2009; Schlinger, 2015). It has been suggested (Hansen et al., 2021) that the previous reported history-dependent increase and decrease of the freely chosen cadence (Hansen et al., 2021) might be caused by neuroexcitation and neuro inhibition, respectively. This suggestion was based on knowledge obtained from animal studies, which focussed on the effects of neurotransmitter substances on stereotyped rhythmic motor output (Frigon, 2017; Majczynski et al., 2020; Miller, 2019). An interpretation of the present observations could be that the impact of inhibitory neuromodulation, caused by submaximal pedalling at a relatively low cadence, can be repealed by 5 min of rest. Further, that more rest appears to be required to be able to avert an impact of excitatory neuromodulation caused by pedalling at a relatively high cadence. Still, it should be emphasised that we cannot exclude quite other mechanisms to play a role in the observations in the present study.

The present study adds to the existing knowledge on the motor behaviour and control of the freely chosen cadence during submaximal pedalling. Thus, it was shown that a brief rest period apparently can cause a weakening of the recently reported phenomenon (Hansen et al., 2021; Hansen & Stilling, 2021) that the freely chosen cadence is dependent on prior cadence. The observations from the present study are of both academic interest and practical relevance. With respect to the latter, the history dependence of the freely chosen cadence should be taken into account when designing protocols for research and testing. The reason is that cadence affects physiological and biomechanical responses such as heart rate, oxygen uptake, efficiency, and pedal force (Hansen, 2015).

It should be noted that freely chosen index finger tapping rate has also been reported to be history-dependent (Nielsen et al., 2022). Thus, from a recent study, which was similar in design to the study by Hansen et al. (2021), it was reported that initial index finger tapping at a preset relatively low target rate caused a subsequent freely chosen rate to be on average about 15% lower than a reference freely chosen rate (Nielsen et al., 2022). Hence, the present, as well as previously observed, history dependence phenomenon for pedalling is not restricted to only that type of activity. However, whether it occurs in yet other stereotyped rhythmic activities have to be investigated in future studies.

Heart rate was on average about 2% higher at the end of sequence B, which was initiated at the relatively high cadence of 90 rpm, as compared to the heart rate at the end of sequence C, which was performed at freely chosen cadence throughout. This result exemplifies that the history dependence in question can indeed affect physiological responses and, thereby, be of practical relevance.

Further, the result supports that history dependence of pedalling rhythmicity potentially is relevant to consider when designing protocols and procedures for fitness testing and research studies, merely to mention two fields of relevance.

Key characteristics of the pedal force profile were not statistically significantly different between sequence C and sequences A and B—at the end of the sequences. This result is counterintuitive when there was a statistically significant difference in cadence (between C and B). The reason is that from a purely mechanical perspective, the maximum tangential pedal force could be expected to decrease during pedalling at constant power output when cadence is increased, and *vice versa*. However, a statistically significant effect of cadence on maximum tangential pedal force can sometimes vanish in a type II error, which is especially the case when cadence is freely chosen and a considerable intra-group variability, therefore, occurs.

The present observations generate new questions. The following should merely be considered as some examples. Does exercise intensity, or power output, play a role in the observed phenomenon? For how long time will the phenomenon be observable if the final bout in the pedalling sequence is prolonged beyond 5 min? Does the duration of the initial bout at preset cadence play a role in the phenomenon? Future studies need to be conducted to answer such questions.

5. Conclusion

History dependence of freely chosen pedalling rhythmicity in a second pedalling bout, performed at freely chosen cadence, was shown to be averted when a 5-min rest period was held between that bout and an initial bout, which was performed at the relatively low preset target cadence of 50 rpm. On the other hand, history dependence did indeed occur when the initial pedalling was performed at the relatively high preset target cadence of 90 rpm. These divergent findings, combined with previous reports of clear history dependence in pedalling sequences (performed similarly to here, only without incorporated rest periods), overall suggest that the present observations reflected a borderland of motor behavioural history dependence. Further, it was the brief rest period that brought about the apparent weakening of the history dependence phenomenon.

Authors' Contributions

EAH formulated the idea of the study. Data collection was performed by ES, JB, GPHB, KEK, ID, and CHFN. Data analysis was performed by all authors. The first draft of the manuscript was written by EAH. All authors contributed to finalising the manuscript. All authors read and approved the final manuscript.

Declarations

Ethical Approval

The present study was performed in line with the principles of the Declaration of

Helsinki. The study conformed to the standards set by the North Denmark Region Committee on Health Research Ethics.

Consent to Participate

Written informed consent was obtained from the participants.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Abbreviations

Fmax	Maximum tangential pedal force
Fmin	Minimum tangential pedal force
rpm	Rounds per minute
SRM	Schoberer Rad Messtechnik