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Original Research

Freely Chosen Cadence is Increased during Repeated Bouts of Submaximal Ergometer Pedalling

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ABSTRACT

International Journal of Exercise Science 15(1): 1142-1155, 2022. It was investigated whether the phenomenon of repeated bout rate enhancement occurs during submaximal ergometer cycling. Repeated bout rate enhancement is defined as an increase of the freely, or spontaneously, chosen cadence during repeated bouts of pedalling and has previously been reported for finger tapping. This is relevant to study since cadence can affect biomechanical and physiological responses. Recreationally active individuals (*n*=27) performed five consecutive 5-min bouts of cycling at 100 W using freely chosen cadence. All bouts were separated by 10-min rest. Cadence, pedal force profile characteristics, heart rate, tympanic temperature, and rate of perceived exertion were determined during cycling. The primary result was that cadence at the end of 5. bout was statistically significantly higher than at the end of all other bouts. Overall, the cadence at the end of 5. bout was 15.6%±20.4% higher than at the end of 1. bout. The altered rhythmic motor behaviour was accompanied by a statistically significant effect of bout on the pedal force profile. Also, there was a statistically significant effect of bout on heart rate, which amounted to 125±17 and 131±26 beats/min at the end of 1. and 5. bout, respectively. Perhaps the observed increase of cadence occurred as a nonconscious rhythmogenesis process in form of a net excitation of relevant parts of the nervous system. In conclusion, repeated bout rate enhancement during submaximal ergometer cycling occurred. The freely chosen cadence showed an increase of on average about 15%, or 10 rpm, as accumulated values across five bouts of cycling.

KEY WORDS: Kinetics, movement control, movement rate, repeatability, rhythmicity, voluntary motor behaviour

INTRODUCTION

Cycle ergometry is widely applied in connection with for example testing of athletes (28, 29, 40) and execution of basic research (19, 38). In addition, cycle ergometry is recommended for physical training (9, 31). During submaximal ergometer cycling, cadence plays a role for the biomechanical and physiological responses of the cyclist. As one example, it is known that maximal effective pedal force, which is the force applied perpendicular to the crank arm, in the direction of rotation, decreases with increasing cadence (8, 35). In addition, it is known that oxygen uptake as a function of cadence forms an approximately J- or U-shaped relationship (10, 23). It is also known that freely chosen cadence in general is higher than the energetically optimal cadence, with the latter defined as the cadence resulting in the nadir of the U-shaped curve. The latter fact causes the oxygen uptake to be about 5% to 7% higher at the freely chosen cadence, as compared to the energetically optimal cadence (23, 25).

Freely chosen, or spontaneous – if you like, cadence during ergometer cycling may be considered a voluntary, stereotyped movement rhythm, which can be generated in a predominantly automated way with modest conscious attention (20, 45). It follows, that such a movement rhythm may be considered to share similarities with other freely chosen rhythms like freely chosen stride rate during locomotion and freely chosen tapping rate during finger tapping (20).

Repeated bout rate enhancement is a phenomenon, which has been reported for freely chosen index finger tapping. The phenomenon constitutes an increase of the freely chosen finger tapping rate across repeated bouts of finger tapping. For example, the freely chosen finger tapping rate increased systematically by an average of approximately 6% to 8% in a second bout performed following an initial bout of tapping (22, 33). It has previously been suggested that perhaps the movement-elicited priming phenomenon of repeated bout rate enhancement is caused by net neuroexcitation in relevant parts of the nervous system, which are involved in the rhythmogenesis (20). A net neuroexcitation could include a moderate release of serotonin in spinal neural networks that could exert excitatory effects on rhythmogenesis (43). For a review on the topic, the reader is referred to a couple of previously published articles (36, 41).

So far, we do not know whether repeated bout rate enhancement also occurs during submaximal ergometer cycling. In other words, whether an increase of the freely, or spontaneously, chosen cadence occurs during repeated bouts of pedalling, which are interrupted by rest periods. However, in the case that it indeed does occur, it is obvious that it might have meaningful consequences for the cyclist's response, including biomechanical and physiological aspects.

Therefore, the purpose of the present study was to investigate whether the phenomenon of repeated bout rate enhancement occurs during submaximal ergometer cycling. An increase of the freely chosen cadence across repeated bouts of ergometer cycling would confirm the occurrence, while no occurrence of the phenomenon would be revealed in case of no effect of bout on the freely chosen cadence.

METHODS

Participants

A sample size estimation performed (www.biomath.info/power/prt.htm) in the design phase of the project resulted in 23 individuals. This estimation was based on a paired *t*-test to be performed with an alpha value of 0.05, an expected mean difference of 5 rpm, an expected mean SD of differences of 8 rpm, and a power of 0.80. To take into account possible dropouts or missing data due to technical errors, 27 individuals were recruited. Twenty-seven (18 males, 9 females) healthy and recreationally active individuals (mean ± SD: 1.76 ± 0.08 m, 77.4 ± 12.8 kg, 25 ± 2 years) participated in the study. They 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 the latter was to avoid any particular conscious control of the cadence when this was freely chosen. Participants were typically university students, who occasionally performed bicycling as transportation or recreation, but none were competitive cyclists. 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. This research was carried out in accordance with the ethical standards of the International Journal of Exercise Science (34).

Protocol

Each participant reported to the laboratory once, for a test session of approximately 90 min duration. During the test session, the participant performed five bouts of submaximal ergometer cycling at freely chosen cadence. The consecutive bouts of cycling were separated by rest periods. Motor behavioural, biomechanical, and physiological responses were measured during cycling.

First, the participant's height and body mass were measured, and age was noted. Next, the seat height of the electromagnetically braked SRM cycle ergometer (Schoberer Rad Messtechnik, Jülich, Germany) was adjusted according to "the heel method" (5). Further, the ergometer's power measuring unit, as well as the Powerforce system for pedal force measurements (Radlabor GmbH, Freiburg, Germany), were reset according to the manufactures' manuals. Thereafter, the participant was instructed regarding the applied light to moderate intensity (100 W, regardless of cadence) and the type of pedalling (freely chosen) that was about to be performed in the following. For the cycling at freely chosen cadence, the following instruction was given: "You must now pedal at a freely chosen cadence. You could try to imagine that you are bicycling outside on a road. There is no correct or incorrect cadence. Simply, pedal as you find it natural". Thus, the participant was not encouraged to maintain a certain cadence across the consecutive bouts of pedalling. Thereafter, five 5-min bouts at 100 W at freely chosen cadence were performed. For this, the cycle ergometer was pre-programmed to maintain a power output of 100 W. Thus, "gear 8" and "constant watt" operating mode on the SRM cycle ergometer were used. This setting ensures a pre-programmed power output regardless of the cycling cadence. The bouts were separated by 10-min rest periods where the participant got off the cycle ergometer and sat on a chair. The participant was blinded for all data, including cadence and heart rate. The participants wore his or her own sports shoes during the ergometer cycling. The pedals were mounted with toe clips.

Cadence was noted every 30 s. A single value of the freely chosen cadence was calculated as a mean across the noted values during the last 3 min, for further analysis.

Effective pedal force (Fe; force directed perpendicular to the crank arm, with positive values in the direction of rotation) from the left and the right pedal were recorded for a duration of 30 s, from 4:15 (min:s) to 4:45. The forces were recorded at 1000 Hz using a 16 bit A/D converter, and the data acquisition LabVIEW-based software IMAGO Record (part of the Powerforce system). For each 30-s recording, the Powerforce system calculated a single mean effective pedal force profile for one revolution, for each of the two pedals. From these profiles, maximal and minimal values of the effective pedal force were found. Mean values of the values from the left and the right pedal were calculated for further analysis. The same recording and analysis were performed for the unused force (Fu; force directed as a continuation of the crank arm, with positive values away from the bottom bracket). For illustrations of pedal force directions and pedal force profiles, the reader is referred to a previous publication (42).

Tympanic temperature was measured immediately before initiation of cycling and again within 20 s after termination of pedalling. At each of these time points, measurements were made twice in order to get robust temperature data. For this, a Braun ThermoScan 7 (Braun GmbH, Kronberg, Germany) was used. Subsequently, mean values from the repeated measurements were calculated for further analysis.

Heart rate was recorded with a Garmin Forerunner 245 (Garmin International Inc., Olathe, KS, USA) and noted every 30th s. Subsequently, a single value of the heart rate was calculated as a mean across the noted values during the last 3 min, for further analysis.

Rate of perceived exertion (RPE) was noted immediately after each bout by applying the 6 to 20 point Borg scale (6).

Statistical Analysis

Tests for normality (Shapiro-Wilks) showed that $p > 0.05$, and data were therefore considered normally distributed. Repeated measures ANOVA was performed to test for an effect of bout on the various measured variables (except RPE). In case of statistically significance, a *t*-test was applied for post hoc analysis. Bonferroni adjustment, dividing the *p*-value of 0.05 by the number (i.e., 4) of tests (i.e., $p \leq 0.013$ was considered statistically significant), was performed to reduce the risk of type I error. Partial eta squared was used for effect size. A Friedman test was performed to test for an effect of bout on RPE as these data are not measured on a ratio scale. For post hoc analysis of the RPE data, a Wilcoxon signed-ranked test with Bonferroni correction was applied. These statistical tests were performed in IBM SPSS 27.0 (SPSS Inc., Chicago, IL, USA). Pearson correlation coefficients and regression equations were calculated by EXCEL 2016 (Microsoft Corporation, Bellevue, WA, USA). The following ratings based on the size of *R* apply to both positive and negative correlations: ≤ .25 is weak, 0.26 to 0.50 is moderate, 0.51 to 0.75 is fair, and ≥ 0.76 is high (2). Unfortunately, some data were lost due to technical errors. Thus, $n = 24$ for data on pedal force profile characteristics and heart rate while $n = 27$ for all other data. All data are presented as mean ± standard deviation (SD), unless otherwise indicated. $p \leq 0.05$ was considered statistically significant, unless otherwise indicated.

RESULTS

Cadence: A repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean cadence at the end of the bouts (i.e., across the last 3 min) differed statistically significantly between bouts ($F(1.548, 40.248) = 13.316$, $p < 0.001$). Effect size was 0.339. For exact values, the reader is referred to the superimposed numbers in figure 1A. Post hoc analysis with Bonferroni adjustment showed that cadence at the end (i.e., across the last 3 min) of 5. bout was statistically significantly higher than at the end of all other bouts (p-values ranged between < 0.001 and 0.003). For exact p-values, the reader is referred to the legend of figure 1. The cadence at the end of 5. bout was 15.6% ± 20.4% higher than at the end of 1. bout. Figure 2 illustrates individual values of change in cadence from the end of 1. bout to the end 5. bout, plotted as a function of cadence at the end of 1. bout.

Fe_max: A repeated measures ANOVA with a Greenhouse-Geisser correction determined that Fe_max at the end of the bout did not differ statistically significantly between bouts ($F(1.939, 44.608) = 3.029$, $p = 0.060$). Data are shown in figure 1C.

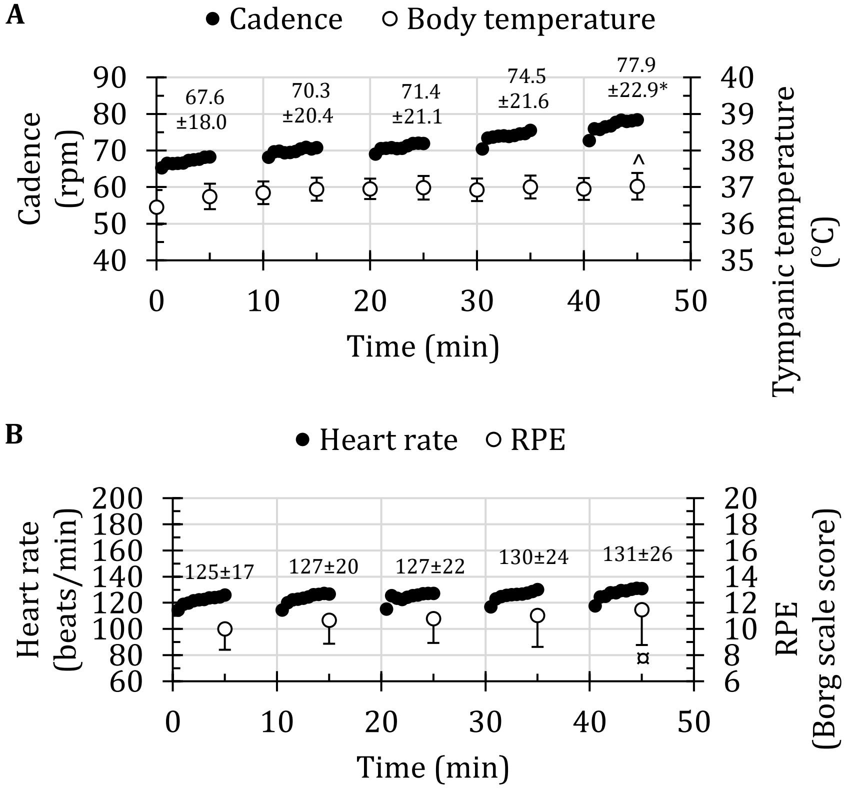

Figure 1. The figure illustrates behavioural, physiological, psychophysiological, and biomechanical variables as a function of time during repeated bouts of submaximal ergometer cycling. **Panel A**: Cadence and tympanic temperature as a function of time. The superimposed written cadence values represent mean ± SD across the last 3 min. *Higher than at the end (i.e., across the last 3 min) of 4. bout ($p = 0.003$), 3. bout ($p = 0.002$), 2. bout ($p = 0.001$), and 1. bout ($p < 0.001$), respectively. ^Higher than following 1. bout ($p < 0.001$). Non-significant p-values for comparisons of temperature following 5. bout with values following, respectively, 4., 3., and 2. bout amounted to

0.561, 0.263, and 0.107. **Panel B**: Heart rate and RPE as a function of time. The superimposed written heart rate values represent mean ± SD across the last 3 min. ¤Higher than for 4. bout ($p = 0.013$) and 1. bout ($p = 0.002$). Non-significant p-values for comparisons of RPE for 5. bout with values for 3. bout and 2. bout were 0.021 and 0.019, respectively. SD-bars for RPE are only presented in one direction, for clearness.

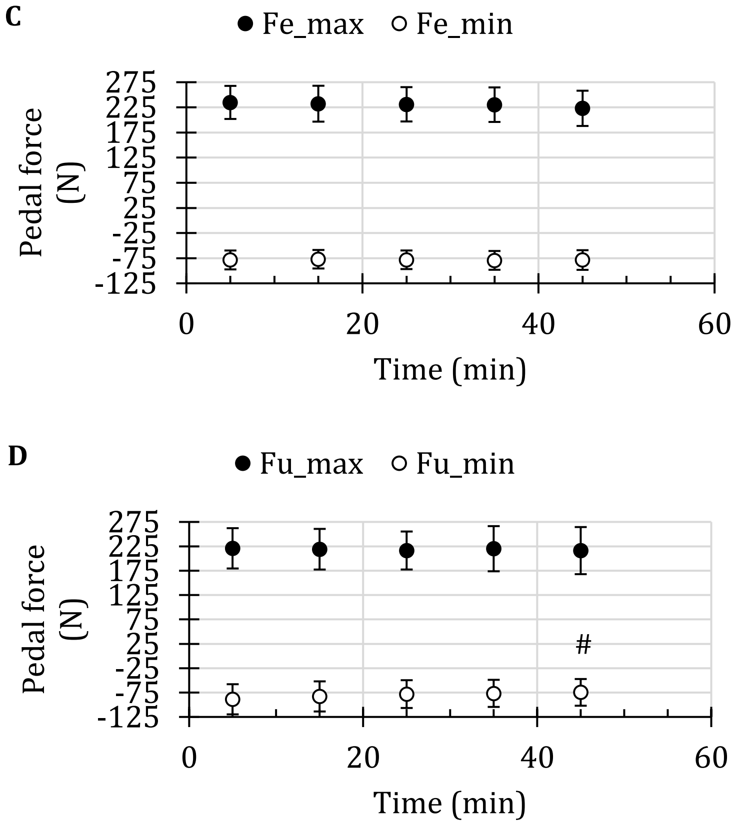

Figure 1 (cont). Panel C: Fe_max and Fe_min as a function of time. **Panel D**: Fu_max and Fu_min as a function of time. #Less negative than at the end of 2. bout ($p = 0.009$) and 1. bout ($p < 0.001$). Non-significant p-values for comparisons of Fu_min for 5. bout with values for 4. bout and 3. bout amounted to 0.393 and 0.122, respectively. Of note is that $p \leq 0.013$ was considered statistically significant, due to Bonferroni correction.

Fe_min: A repeated measures ANOVA with a Greenhouse-Geisser correction determined that Fe_min at the end of the bout did not differ statistically significantly between bouts (F(1.654, 38.052) = 0.660, $p = 0.495$). Data are shown in figure 1C.

Fu_max: A repeated measures ANOVA with a Greenhouse-Geisser correction determined that Fu_max at the end of the bout did not differ statistically significantly between bouts (F(1.782, 40.978) = 0.344, $p = 0.686$). Data are shown in figure 1D.

Fu_min: A repeated measures ANOVA with a Greenhouse-Geisser correction determined that Fu_min at the end of the bout differed statistically significantly between bouts (F(2.068, 47.570) = 8.356, $p = 0.001$). Effect size was 0.266. Post hoc analysis with Bonferroni adjustment showed that Fu_min was statistically significantly less negative at end of 5. bout as compared to 2. bout and 1. bout. Data are shown in figure 1D. For exact *p*-values, the reader is referred to the legend of figure 1.

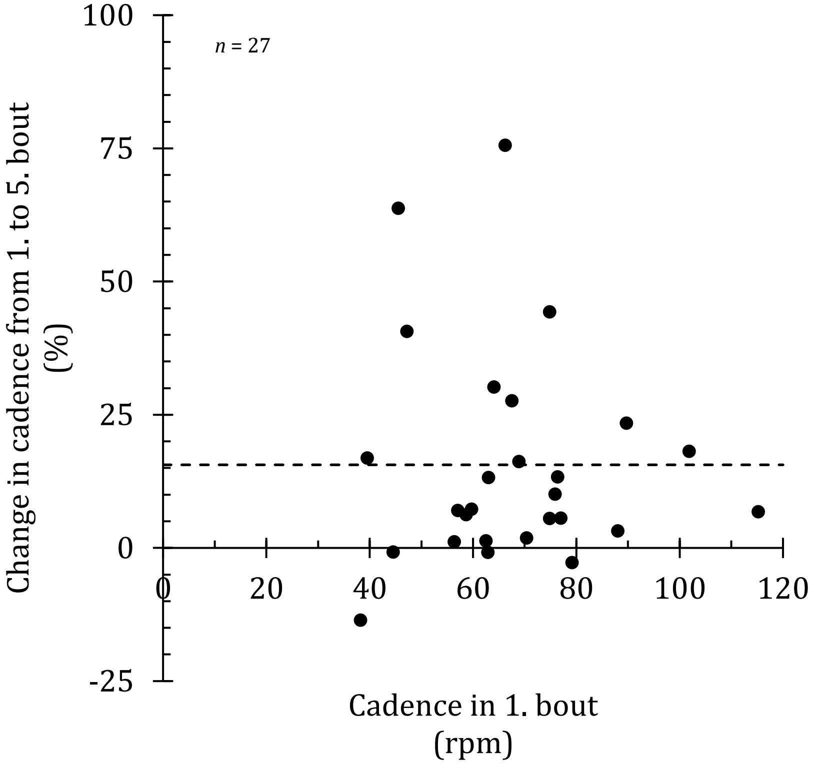

Figure 2. The figure illustrates the change of freely chosen cadence from end of 1. bout (i.e., across the last 3 min) to end of 5. bout, plotted as a function of the cadence at the end of 1. bout. Each data point represents a single participant. The broken line illustrates the average increase of 15.6% for the entire group of participants.

Tympanic temperature: A repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean tympanic temperature, measured following the bouts, differed statistically significantly between bouts ($F(2.340, 60.832) = 12.281$, $p < 0.001$). Effect size was 0.321. Post hoc analysis with Bonferroni adjustment showed that the tympanic temperature was statistically significantly higher following 5. bout than following 1. bout. For exact *p*-values, the reader is referred to the legend of figure 1.

Heart rate: A repeated measures ANOVA with a Greenhouse-Geisser correction determined that heart rate differed statistically significantly between bouts ($F(1.338, 30.774) = 3.789$, $p = 0.050$). Effect size was 0.141. For exact values, the reader is referred to the superimposed numbers in figure 1B. Post hoc analysis with Bonferroni adjustment, though, did not detect statistically significant differences between 5. bout and any of the other bouts (*p*-values were between 0.036 and 0.115).

RPE: A Friedman test determined that RPE differed statistically significantly between bouts ($\chi^2(4) = 23.978$, $p < 0.001$). Post hoc analysis with Wilcoxon signed-ranked tests was conducted with a Bonferroni correction and showed that RPE was statistically significantly higher for 5. bout as compared with 4. bout and 1. bout. For exact *p*-values, the reader is referred to the legend of figure 1.

Table 1. Result of correlation and regression analyses of within-bout and between-bout test-retests of key variables.

x	y	n	**Equation**	R^2	p
Freely chosen cadence 1. bout, 2. last measurement	**Freely chosen cadence** 1. bout, last measurement	27	$y = 1.022x - 1.358$	0.991*	< 0.001
Freely chosen cadence 1. bout, avg. of last 3 min	**Freely chosen cadence** 2. bout, avg. of last 3 min	27	$y = 1.109x - 4.650$	0.957*	< 0.001
Fe_max 1. bout, end of bout	**Fe_max** 2. bout, end of bout	24	$y = 1.003x - 3.282$	0.856*	< 0.001
Tympanic temperature Before 1. bout, 1. measurement	**Tympanic temperature** Before 1. bout, 2. measurement	27	$y = 0.853x + 5.400$	0.902*	< 0.001
Tympanic temperature After 1. bout, avg. of two measurements	**Tympanic temperature** After 2. bout, avg. of two measurements	27	$y = 0.648x + 13.121$	0.515*	< 0.001
Heart rate 1. bout, 2. to last measurement	**Heart rate** 1. bout, last measurement	24	$y = 0.966x + 5.710$	0.956*	< 0.001
Heart rate 1. bout, avg. of two last measurements	**Heart rate** 2. bout, avg. of two last measurements	24	$y = 1.152x - 17.287$	0.958*	< 0.001
RPE 1. bout	**RPE** 2. bout	27	$y = 0.970x + 0.970$	0.739*	< 0.001

*Statistically significant.

Test-retest data reproducibility: To investigate data reproducibility, a test-retest analysis, in form of correlation and regression analyses, was performed for a number of key variables of the present study. Some tests were performed to determine consecutive-measurement-repeatability, within a bout. Other tests were performed to determine between-bout-repeatability. The result of the test-retest analysis is presented in table 1. Briefly, consecutive measurements of freely chosen cadence within a bout showed the highest reproducibility ($R = 0.995$). Between-bout tympanic temperature showed the lowest reproducibility ($R = 0.718$).

DISCUSSION

Overall, the values of most of the measured variables of the present study are in line with previously published data. That statement is based on comparisons with data collected in studies using similar participants who also performed ergometer cycling at 100 W, as in the present study. For example, heart rate during ergometer cycling at 100 W at 60 rpm has previously been reported to be on average 123 bpm (7). For comparison, heart rate during 1. bout in the present study, in which cadence was on average 67.6 rpm, was on average 125 bpm. As another example, tympanic temperature during ergometer cycling at 100 W at 60 rpm has previously been reported to be on average 37 °C after 5 min of cycling (44). This is similar to the data from the present study. Of note is that tympanic temperature has been reported to be on average 0.7 °C lower than rectal temperature (16). However, the temperature measurements also showed a high interclass correlation coefficient (0.86), as calculated using data from the two different measurement methods (16). As yet another example, RPE has been reported to be on average about 10 for "normal" subjects during ergometer cycling at 10 mkp s^{-1} (≈ 100 W) at 60 rpm (30). That is similar to the average RPE-value from 1. bout in the present study. As a final example, freely chosen cadence during ergometer cycling at 100 W has been reported to be on average 72.4 rpm during one of three cycling bouts, which were performed in a counterbalanced order (24). That value is similar to the average freely chosen cadences measured across the bouts in the present study.

The present results from the test-retest analysis might contain useful information in order to plan future studies. The information on test-retest reproducibility is for example useful for estimation of an appropriate number of participants in a study. Freely chosen cadence has previously been reported to have a high between-bout-reproducibility, with a correlation coefficient of 0.84 (21). For comparison, it was 0.978 in the present study. Moreover, freely chosen cadence has been reported to have a high reproducibility between days, with a between-day intraclass correlation coefficient (*ICC*) of 0.91 (26). It is obvious from the present study that in the case that tympanic temperature is the major outcome variable in an intervention study applying two exercise bouts, more participants appears to be appropriate than if freely chosen cadence is the major outcome variable. This comparison of course presumes a similar expected percentage effect of an intervention, since the expected magnitude of the effect also affects the appropriate number of participants. The present reproducibility analysis supports the likeliness of type 2 errors for the observed non-significant effects of bout on pedal force profile characteristics, as there was a significant effect of bout on freely chosen cadence. Thus, the between-bout-reproducibility was lower for the Fe_max than for freely chosen cadence. Of note is that test-retest analyses, including for RPE (30) and pedal force (24, 26, 39), are reported previously.

The phenomenon of repeated bout rate enhancement for freely chosen cadence during submaximal ergometer cycling, which was the primary observation of the present study, has not been reported before, according to the best of our knowledge. Thus, the 15.6% ± 20.4% increase of cadence across the five bouts in the present study constitutes a novel finding.

Though, the phenomenon has been reported for freely chosen tapping rate during index finger tapping. As an example, the freely chosen tapping rate increased by 8.2% ± 5.4% across four bouts of tapping (22). In line with that, the freely chosen tapping rate was reported to increase by 6.0% ± 11.0% in the second of two consecutive bouts of tapping (33). It applies to both these examples from previously conducted studies that each tapping bout lasted 3 min.

It has been suggested that freely chosen cadence during submaximal cycling represents an inherent voluntary stereotyped rhythmic leg movement rate, under primary influence of spinal rhythm-generating neural networks, termed central pattern generators (CPGs) (25, 27, 37). In other words, that freely chosen cadence might be a useful reflection of CPG-mediated rhythmogenesis. In addition, it should be noted that such a type of movement rate presumably is a result of a tripartite interplay between descending supraspinal tonic drive, CPG activity, and sensory feedback (12, 17, 32, 45). Yet, with major influence from CPGs. For comparison, accurate non-blinded pedalling at an exact certain preset target cadence would be presumed to be generated with more conscious, and thereby supraspinal, control. A similarity between finger tapping and pedalling at freely chosen cadence is the possibility of automated, and to a large extent nonconscious, control of the movements. On the other hand, it is obvious that single-hand index finger tapping is a unilateral movement performed with relatively small hand muscles, compared with the bilateral movement of pedalling performed with relatively large leg muscles, and that there are other apparent differences between freely chosen finger tapping rate and freely chosen cycling cadence.

A possible explanation of the present observed repeated bout rate enhancement could involve neuromodulation, in form of net excitation. Thus, perhaps the increased freely chosen cadence across the bouts in the present study reflects a net neuroexcitation caused by neurotransmitters. A net neuroexcitation could have occurred in the supraspinal regions involved in the rhythmogenesis, in spinal CPGs, or in both locations. A net neuroexcitation could result from a moderate release of serotonin into synapses that could exert excitatory effects on movement genesis (43). The reader is referred to a couple of previous publications (36, 41) for a review on the topic. In addition, it has been suggested, based on human studies, that electrical stimulation of afferents can modify the excitability of human spinal CPGs (13, 14). Furthermore, experiments involving spinal cord-injured humans have shown that spinal cord stimulation combined with pharmacological neuromodulation causes excitation of the spinal circuitry (1, 15). Theoretically, temperature could play a role for rhythmogenesis, which was a reason why temperature was of interest in the present study. The background for the consideration is that a review of animal studies has summarised that warming or cooling CPG elements respectively speeds up or slows down the rhythm, or sequence rate, in rhythmic movement (4). However, an apparent relationship between temperature and rate enhancement was not observed in the present study. Thus, after a slight increase in tympanic temperature from 1. to 2. bout, the temperature practically remained constant for the remainder of the bouts while the freely chosen cadence continued to increase. Of note is also, that an increase of merely 0.5 °C occurred in the present study. In animal studies showing an effect of temperature on spinal neural network rhythm output, temperature was e.g. changed by 2.5 °C or more (11).

The present novel finding of repeated bout rate enhancement for freely chosen cadence during submaximal ergometer cycling is of practical relevance. As an example, the phenomenon should be considered when designing research studies and interpreting results of already performed studies, which includes consecutive bouts of pedalling at freely chosen cadence. The reason is that, as described in the introduction, cadence may affect biomechanical and physiological responses. Eventually, such response effects may affect human performance. Indeed, the present study confirmed that cadence enhancement was accompanied by heart rate as well as a pedal force profile changes. Heart rate closely reflects oxygen uptake (3), and thereby metabolic rate, during submaximal exercise. A comparable size of heart rate increase as in the present study, for a comparable increase of cadence, has been reported previously (25). In support of the observed, in practice, constant tympanic temperature, despite an increase of cadence, during the last four bouts in the present study, rectal temperature has been reported not to be affected by an increase from 60 to 90 rpm in a previous study (18). That finding by Hagan *et al.* (1992) occurred despite simultaneous increases of heart rate, oxygen uptake, and pulmonary ventilation. Regarding the higher score of RPE across the performed bouts, it should be noted that the increase was modest and could reflect incipient mild fatigue due to the repeated exercise.

In conclusion, the phenomenon of repeated bout rate enhancement, which has previously been reported for finger tapping, was observed during submaximal ergometer cycling in the present study. Thus, the freely chosen cadence showed an accumulated increase of about 15% across five consecutive 5-min bouts of ergometer cycling, which were interrupted by 10-min rest periods.

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