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Freely chosen stride frequencies during walking and running are not correlated with freely chosen pedalling frequency and are insensitive to strength training

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ABSTRACT

Despite biomechanical differences between walking, running, and cycling, these types of movement are supposedly generated by shared neural networks. According to this hypothesis, we investigated relationships between movement frequencies in these tasks as well as effects of strength training on locomotion behaviour. The movement frequencies during walking, running, and cycling were 58.1 ± 2.6 strides min^{-1}, 81.3 ± 4.4 strides min^{-1}, and 77.2 ± 11.5 revolutions min^{-1}, respectively ($n = 27$). Stride frequencies in walking and running correlated positively ($r = 0.72$, $p < 0.001$) while no significant correlations were found between stride frequencies during walking and running, respectively, and pedalling frequency ($r = 0.16$, $p = 0.219$ and $r = 0.04$, $p = 0.424$). Potential changes in the freely chosen stride frequencies and stride phase characteristics were also investigated during walking and running through 4 weeks of (i) hip extension strength training ($n = 9$), (ii) hip flexion strength training ($n = 9$), and (iii) no intervention ($n = 9$). Results showed that stride characteristics were unaffected by strength training. That is in contrast to previous observations of decreased pedalling frequency following strength training. In total, these results are proposed to indicate that walking and running movements are robustly generated due to an evolutionary consolidation of the interaction between the musculoskeletal system and neural networks. Further, based on the present results, and the fact that cycling is a postnatally developed task that likely results in a different pattern of descending and afferent input to rhythm generating neural networks than walking and running, we propose pedalling to be generated by neural networks mainly consolidated for locomotion.

1. Introduction

Walking, running, and cycling are common voluntary human rhythmic movements. A proper functionality in these motor tasks is an important factor for human quality of life. Moreover, a better understanding of the control mechanisms of such movement tasks is desirable for exercise and rehabilitation purposes [1].

Rhythmic movements across vertebrate species are coordinated by neural networks located in the brain and the spinal cord. The spinal components of these neural networks are termed central pattern generators (CPGs), which generate an organized pattern of motor activity in combination with adequate supraspinal descending and peripheral afferent influences [2–4]. The existence of CPGs and homolog interneurons has been proven in several vertebrate species (lampreys, mice, cats) [5]. However, it has been difficult to directly prove the existence of CPG function in primates [6] and humans. Indirect evidence of existence of functional CPG-like spinal neural networks has been reported in patients with spinal cord injuries [7,8] and in infants [9]. As such, the analysis of motor behaviour can be used to increase our knowledge of nervous system organization and function [10].

According to the "common core hypothesis" [3], walking, running, and cycling may share common central mechanisms. In support of this hypothesis, it has been shown that timing of muscle activation in running can be described by the same basic temporal activation components that previously had been reported for walking [11]. The authors of the latter study have suggested that despite of distinct biomechanical differences between walking and running, these movements are likely to be controlled by shared pattern-generating networks. Additionally, a similarity of muscle

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synergies during walking and cycling has been reported. This may in turn indicate similar synergies and modular control across different rhythmic movement patterns [12].

Freely chosen pedalling frequency has previously been studied on a cycle ergometer [13], and it most likely reflects an innate voluntary rhythmic leg movement frequency linked to CPG function [3,14]. It has been reported [15], and subsequently confirmed [16], that 12 weeks of leg strength training combining hip extension and flexion exercises, caused recreationally active individuals to reduce their freely chosen pedalling frequency. Furthermore, we recently reported that 4 weeks of hip extension strength training reduced the freely chosen pedalling frequency in recreationally active individuals [13]. Based on these results, it could be speculated that the freely chosen frequency in other rhythmic movements, such as walking and running, would also be affected by strength training.

We hypothesized that (1) freely chosen movement frequencies measured during walking, running, and cycling correlate with each other, and that (2) freely chosen movement frequencies during walking and running are decreased by a period of strength training as observed previously in cycling [15,16].

2. Methods

2.1. Individuals

Twenty seven recreationally active individuals (14 men/13 women, age 24 ± 5 years, height 1.78 ± 0.09 m, and body mass 70.2 ± 10.6 kg) volunteered. The study population was the same as in our recent study [13]. The study was approved by the North Denmark Region Committee on Health Research Ethics (N-20110025) and conformed to the standards of the Declaration of Helsinki.

2.2. Experimental design

The individuals were randomly divided into groups. A HET group ($n = 9$) performed hip extension strength training, while a HFT group ($n = 9$) performed hip flexion strength training. In addition, a CON group ($n = 9$) was not exposed to training. The study lasted 6 weeks, including 4 weeks of training. The individuals completed the following: Familiarization and one repetition maximum (i.e. the maximum load that could be lifted in one repetition, 1RM) strength test, a pretest session, test A1 after 1 week of training, test A2 after 2 weeks of training, test A3 after 3 weeks of training, and finally a posttest session and a second 1RM strength test after 4 weeks of training. The training consisted of two sessions per week, separated by at least 1 day.

2.3. Familiarization and determination of maximal strength

The individuals were familiarized with all procedures including 1RM strength testing, treadmill walking and running, and ergometer cycling. Height, body mass, and leg length were measured. Leg length was defined as the distance between the top of the anterior superior iliac spine to the bottom of the lateral malleolus [17]. Next, the 1RM was determined for leg extension in HET and for leg flexion in HFT (Fig. 1A and B). Determination of 1RM in CON was done so that five individuals performed leg extension and four individuals performed leg flexion. Strength tests were always preceded by 10 min warm-up on the cycle ergometer, at 100 W. Then, individuals performed a standardized strength testing protocol. For more details see [13]. For the strength testing and training, a Plamax Adjustable Pulley (Impulse Health Tech Ltd. Co., Jimo, Qingdao, Shandong Province, China) was used. Walking and running were performed on a motorized treadmill (Trimline 7200, Tyler, TX, USA). Cycling was performed

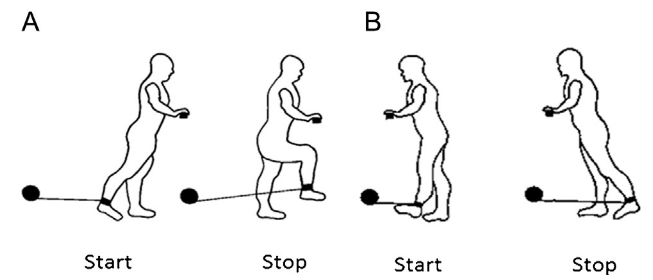

Fig. 1. Progressive strength training was performed with both legs, 2 days per week, for 4 weeks. (A) HFT performed hip flexion training. (B) HET performed hip extension training.
The figure is a modification of Fig. 2 in [13].

on an SRM cycle ergometer (Schoberer Rad Messtechnik, Jülich, Germany) adjusted according to each individual's preference for settings of seat and handlebar [13].

2.4. Test sessions

The individuals always reported to the laboratory at the beginning of the week, at the same time of the day. First, two pressure-sensitive sensors (SFR174, I.E.E., Contern, Luxembourg) were skin-mounted with adhesive tape under each sole of the two feet. Positions were (1) under 2nd and 3rd metatarsal heads, and (2) under the centre of heel pad. The four sensors were connected to custom-built amplifiers, and the signals were sampled at 2000 Hz, through a 16 bit A/D converter, using a custom made LabVIEW-based software (LabVIEW, Austin, TX, USA). Next, the individuals performed 5 min of walking at 4.0 km h^{-1} immediately followed by 5 min of running at 8.4 km h^{-1}. These velocities were chosen to represent light to moderate intensities. Locomotion was performed in a preferred way.

The LabVIEW-based software computed and saved (based on onset/offset detection) stride duration, stance phase, and swing phase. Further, it calculated stride frequency for each foot during the last minute of each locomotion bout. Then, the first ten error-free strides within the recording period were selected for further analysis. Next, mean values across the two feet of each of the stride characteristics were calculated. Afterward, a single mean of these values across the ten strides was calculated for each stride characteristic, to be used in the further analysis.

Approximately 5 min after the running bout, the individuals performed 6 min of ergometer cycling at freely chosen pedalling frequency, at 100 W, corresponding to light to moderate intensity. Pedals with toe clips were used. Gear 8 and "constant Watt" operating mode was selected on the cycle ergometer. This mode ensures a constant power output regardless of pedalling frequency. The freely chosen pedalling frequency was noted at the end of each minute and a mean value was calculated across the last 5 min. Data on pedalling frequencies from Test A1 and beyond are reported elsewhere [13].

Absolute, rather than relative, values of ergometer cycling power output and locomotion velocities were chosen since participants were relatively homogenous with respect to daily activity level.

2.5. Strength training

All training sessions were supervised. They started with a 10 min warm up at self-selected intensity on the cycle ergometer followed by two to three warm up sets with gradually increasing load. Both legs were trained in an alternated way. The exercises performed in HET and HFT were identical to those performed in the