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Changes to gait speed and the walk ratio with rhythmic auditory cuing

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ABSTRACT

Background: Step length and cadence (i.e., step frequency or steps/minute) maintain an invariant proportion across a range of walking speeds, known as the walk ratio (WR = step length/cadence). While step length is a difficult parameter to manipulate, cadence is readily modifiable using rhythmic auditory cuing (RAC; e.g., synchronizing step timing to a metronome or music tempo).
Research Question: The purpose of this study was to determine the effects of RAC-guided cadences on enacted cadence, step length, WR, and gait speed during overground walking.
Methods: Sixteen healthy young adults repeatedly crossed a GAITRite electronic walkway while attempting to synchronize step timing to RAC-guided (metronome) tempos of 80 to 140 beats per minute. Mean absolute percent error (MAPE) was used to compare RAC tempos to enacted cadence. Repeated-measures analyses of variance were performed to test for the effects of RAC on cadence, step length, WR, and gait speed. Moreover, simple linear regressions were used to determine the precise stepwise relationship between RAC conditions and each variable.
Results: Participants successfully matched their cadence to RAC beats (MAPE < 1.1%). Cadence increased proportionally to RAC (linear regression slope = 1.02), while step length also increased but at a slower rate (slope = 0.40). These dissimilar slopes resulted in a modified WR that systematically decreased with increasing cadence, although ultimately gait speed increased with increasing cadence (slope = 1.41). This relationship indicates that every 10 steps/minute incremental increase in cadence corresponded with a 14 cm/s increase in gait speed.
Significance: Gait speed appears to increase in a predictable manner when cadence is guided by RAC during overground walking irrespective of apparent changes to the WR.

1. Introduction

Metabolic intensity (measured as oxygen consumption) exhibits a curvilinear association with gait speed [1,2]. Considering the importance of intensity in physical activity public health guidelines [3], gait speed is a highly scrutinized parameter in physical activity research. Quantifying specific gait speeds that correlate with benchmark intensity values (i.e., 3 metabolic equivalents [METs]) that are associated with reduced risk of all-cause mortality and cardiovascular disease [4] can inform public health guidelines and clinical practice. However, real-time computation of gait speed is often not feasible or practical in the free-living setting because it requires exact and instantaneous measures of both distance and time, or wearable technology enabled with global positioning satellite (GPS). For this reason, a more practical and easily modifiable gait parameter may help to manage locomotor behavior that correlates with beneficial health outcomes.

While gait speed itself is challenging to assess in real-time, other gait parameters that influence speed may be readily measured and manipulated. Gait speed is a product of step length and cadence (i.e., step frequency or steps/min). Importantly, step length and cadence appear to maintain an invariant relationship across a range of overground and treadmill walking speeds [5–10]. That is, as one variable increases, the other increases proportionally. This relationship, known as the walk ratio (WR), is calculated by dividing step length by cadence, and is expressed in units of mm/steps/min. The WR for men and women is ~ 7 mm/steps/min and 6 mm/steps/min, respectively [10]. The WR may represent an innate tendency for locomotor self-

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optimization that minimizes metabolic cost of walking [10–13] and gait variability (e.g., the standard deviation of stride times during steady state walking) [14]. Moreover, the WR may be a useful and accessible index for clinical gait analysis, as it can be used to differentiate healthy individuals (WR ~ 6.4 mm/steps/min) from those with varying levels of disability. For example, individuals with multiple sclerosis who have very mild or moderate disability report WRs ~ 5.5 and 4.9 mm/steps/min, respectively [15,16].

In practice, step length is not a facile parameter to precisely manipulate, whereas cadence is more readily modifiable with rhythmic auditory cuing (RAC) [17–20]. RAC consists of instructing participants to synchronize their cadence to the beat of an auditory metronome or music. Laurent and Pailhous [21] reported that overground gait speed increased linearly as RAC-guided cadences increased. However, the authors noted that step length did not increase proportionally, likely an effect of the implemented constraint on cadence. The differential changes to step length with RAC-guided cadences would theoretically yield a modified WR. Similarly, RAC-guided cadence on a treadmill, which simultaneously constrains gait speed and cadence, results in a modified WR. Specifically, Bertram [22] provided evidence that the rate of increasing step length slows at higher cadence manipulations during treadmill walking.

The findings by Bertram [22] and Laurent and Pailhous [21] suggest that the WR changes when any component of gait is constrained (e.g., speed constrained in treadmill walking, or overground cadence constrained with RAC). If this is accurate, knowledge of the exact change in the WR would be needed to accurately predict gait speeds from RAC-guided overground cadence. Moreover, the precision and utility of using RAC-guided cadence to ultimately yield specific and meaningful gait speeds (i.e., those associated with metabolic intensity levels) during overground walking remains unclear. Previous studies manipulating overground cadence have commonly evaluated changes based on percentages of participants' preferred walking cadence (i.e., relative cadences [21,23]). This design does not allow for the generalizability and convenience of prescribing absolute cadence values (e.g., 80, 100, or 120 steps/min). If the WR changes in a specific and predictable value in response to constrained cadence during normal overground walking speeds, prescribing cadence may be an easily implemented strategy for promoting predictable gait speeds.

Therefore, the purpose of this study was to determine the effects of RAC-guided cadence on enacted (i.e., actual, observed) cadence, step length, WR, and gait speed. Based on previous studies [24–26], we hypothesized that step length would increase at a slower rate than cadence, yielding a lower WR at higher cadences. Additionally, we hypothesized that increasing cadence would yield a predictable increase in gait speed regardless of a disrupted WR.

2. Methods

2.1. Participants

Sixteen healthy, young adults (8 female, mean ± SD, aged 22.4 ± 2.7 years, mass 57.9 ± 3.5 kg, height 168.0 ± 5.7 cm, BMI 20.5 ± 1.5 kg/m^2; 8 male, aged 28.0 ± 3.4 years, mass 80.7 ± 11.9 kg, height 180.2 ± 4.5 cm, BMI 24.8 ± 3.5 kg/m^2) volunteered for this study. All participants self-reported no neurological or vestibular disorders, or any orthopedic issues that could affect walking. All participants provided written informed consent. The protocol was approved by the University Institutional Review Board.

2.2. Experimental apparatus

Participants repeatedly walked over an electronic walkway (GAITRite, CIR Systems Inc., Sparta, NJ, USA). This walkway is 7 m long, 0.9 m wide, and 6 mm high, with an active area of 6.1 x 0.6 m, and has embedded pressure-activated sensors that allow for collecting temporal and spatial information about each foot strike.

2.3. Procedure

Participants wore their own casual shoes and clothing. Participants walked a straight pathway over the GAITRite, which was located in a hallway between two cones (13 m apart). Participants completed continuous back-and-forth crossings of the mat, circling a cone at each end. The cones were placed 3 m beyond the end of the mat at each end to minimize participants' walking acceleration or deceleration when walking over the GAITRite (total distance between cones = 13 m). RAC was produced using a smartphone auditory metronome app (MetroTimer version 3.3.2, ONYX Apps), amplified through a dual speaker system. Participants were instructed to attempt to match their heel strike timing to the sound of the metronome for each step. Participants were instructed to walk (not run) as 'normally' as possible, and informed that gait characteristics would be collected. They were purposely not provided instructions related to their selected gait speed, as a main outcome was contingent upon what speed naturally emerged at different cadences. Each participant completed seven randomly assigned trials at the following metronome tempos: 80, 90, 100, 110, 120, 130, and 140 beats per minute (bpm). For each trial, the participant walked back and forth across the GAITRite 6 times (i.e., 12 crossings). The first two crosses served as practice walks to allow for adjustment to the new cadence, and data were collected for the remaining ten crosses. Each trial was followed by a 2-minute standing rest period. Additionally, participants were informed that, if needed, they could rest after fully crossing the GAITRite, to minimize the risk of fatigue.

2.4. Data processing

Gait spatiotemporal parameters (cadence, step length, WR, and gait speed) were analyzed using the GAITRite software. Each identified foot strike location was visually verified to ensure it was entirely on the mat, and that the auto-detection software identified the correct foot. Manual corrections were made when needed (e.g., incomplete electronic footprints were censored from the data). Step length and WR were assessed separately for each leg.

2.5. Data analyses

Data were averaged within each crossing, and then across all crossings for each trial. To determine the extent of metronome adherence, mean absolute percent error (MAPE) values were obtained for RAC versus enacted cadence:

$$MAPE = \frac{|Enacted \quad Cadence - RAC|}{RAC} * 100 \quad (1)$$

where 'RAC' refers to the auditory metronome (in bpm), and vertical bars || indicate absolute values. The WR was quantified as:

$$Walk \quad Ratio = \frac{Step \quad Length}{Cadence} \quad (2)$$

where step length was calculated in millimeters, and cadence in steps/min. The calculated WR values were expressed in mm/steps/min. In addition, previous studies have indicated that the WR should be adjusted for height [7,9,16]. Following the conventions of Rota and colleagues [16], step length was normalized by dividing it by the ratio between group average height and individual height, and cadence by multiplying it by the square root of the ratio between individual height and group average height. The height-adjusted WR was defined as the ratio between the height-adjusted step length and the height-adjusted cadence.