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VARYING TREADMILL SPEED AND INCLINATION AFFECTS SPONTANEOUS SYNCHRONIZATION WHEN TWO INDIVIDUALS WALK SIDE BY SIDE

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ABSTRACT

Studying spontaneous synchronization of stepping as two individuals walk on side-by-side treadmills may be useful for understanding the control of bipedal locomotion and may have implications for gait rehabilitation. Existing data suggest that this behavior is related to differences in leg length, walkway slope, and over-ground speed between partners, and might be promoted by altering these variables. This idea was evaluated here as 24 pairs of subjects stepped on side by side treadmills under several conditions of relative speed and slope. Overall, pairings that demonstrated very little spontaneous synchronization with the same treadmill speed and slope exhibited significant increases in this behavior when one treadmill was manipulated. Conversely, pairings that demonstrated a tendency to synchronize under normal conditions exhibited significant decreases in this behavior when either treadmill was altered.

Keywords: Locomotion, entrainment, gait rehabilitation

INTRODUCTION

During normal walking, humans will often synchronize their steps with external cues (Nessler & Gilliland, 2009a; Roerdink, et al., 2007; Strogatz, et al., 2005; Thaut, et al., 1996; van Ulzen, et al., 2008; Zivotofsky & Hausdorff, 2007). For individuals with mild to moderate gait pathology, this behavior might be useful for improving function, and intentional synchronization with a metronome has yielded beneficial effects in multiple patient populations (Cubo, et al., 2004; Pelton, et al., 2009; Rochester, et al., 2009; Roerdink, et al., 2007; Roerdink, et al., 2009; Thaut, et al., 1996). However, forced synchronization may not be optimal for promoting recovery in certain individuals, as healthy locomotion generates patterns in stride time that cannot be reproduced by a metronome (Hausdorff, et al., 1996; Nessler, et al., in press). In addition, this practice has been shown to alter an individual's normal stride length and swing velocity (Nessler & Gilliland, 2010a).

Unintentional or spontaneous synchronization of stepping may be preferable to forced synchronization, as the former does not affect step kinematics in the same manner (Nessler, et al., 2009b; Nessler & Gilliland, 2010a; Nessler, et al., in press). Spontaneous synchronization can be elicited through side by side walking, where the external cue arising from one's partner is consistent with normal human stride interval dynamics (Nessler, et al., in press). In addition, a passive control strategy is used to achieve synchronization that involves fewer active, corrective movements (Beek & Turvey, 1992; Milton, et al., 2004), and side by side walking may promote greater activation of the mirror neuron system (Cochin, et al., 1999; Kohler, et al., 2002; Rizzolatti & Craighero, 2004). While additional study is needed, initial investigation suggests

that side by side walking may result in alterations to stepping that are desirable for rehabilitation (Nessler, et al., 2009b; Nessler, et al., in press).

Unfortunately, the occurrence of spontaneous synchronization is varies greatly among pairings, and difficulties with promoting this interaction between partners could potentially undermine therapeutic benefits (Nessler, et al., 2009b; Nessler & Gilliland, 2008). For example, previous studies have reported the occurrence of spontaneous synchronization to be between 50-60% for healthy individuals, while intentional synchronization can be typically be achieved at will (Nessler, et al., 2009b; Nessler & Gilliland, 2009a; van Ulzen, et al., 2008; Zivotofsky & Hausdorff, 2007). Further, many couples tend to move in and out of synchrony during extended periods of side by side stepping, which may also reduce training effects and alter stepping mechanics (Nessler & Gilliland, 2009a; van Ulzen, et al., 2008). While it may not be possible to directly enforce spontaneous synchronization, understanding the factors that contribute to this behavior may allow for the subtle promotion of entrainment in situations where synchronization is unreliable or absent. Therefore, additional investigation is needed to further define the mechanical and sensory contributions to entrainment during side by side walking, as these characteristics are currently not well understood.

Previous investigation suggests that spontaneous synchronization is related to the pendulum-like dynamics of bipedal locomotion, and is relatively robust to changes in sensory information (Nessler & Gilliland, 2009a). In particular, partial attenuation of visual and auditory information regarding the stepping activity of one's partner does not significantly alter the occurrence of spontaneous synchronization (Nessler & Gilliland, 2009a). On the other hand, both the occurrence and quality of entrainment are related to differences in leg length between

partners (Nessler & Gilliland, 2009a). Taken together, these results suggest that under favorable biomechanical conditions, only a small amount of sensory information is necessary for spontaneous synchronization to occur. Further, manipulation of certain biomechanical properties of gait may have a stronger effect on the occurrence of synchronization and may therefore be used to promote synchronization.

Based upon this premise, simulations of paired walking were carried out using a well-known passive dynamic walking model (Garcia, et al., 1998) with a spring modeled between the legs to provide control of hip actuation through adjustments in spring stiffness (Kurz, et al., 2008). This model demonstrated that synchronization can be achieved in walkers with different leg lengths by controlling hip actuation together with alterations in the walkway slope or over-ground speed of one of the walkers with respect to the other (Nessler, 2009c). In humans, walking on a slope results in behavior that is similar to that demonstrated by the walking model, suggesting that alterations in these mechanical properties may bring an individual's preferred cadence closer to that of their partner, thereby increasing the likelihood that synchronization might occur spontaneously (Leroux, et al., 2002; McIntosh, et al., 2005).

The purpose of this study was to empirically test the prediction that spontaneous synchronization might be influenced by interpersonal changes in the mechanics of gait, namely relative over-ground speed and walkway slope. For individuals that do not demonstrate spontaneous synchronization under normal conditions, it was hypothesized that these factors were not preferentially tuned. Therefore, each of the following would promote synchronization among these pairings: increasing the speed of the taller subject's treadmill, declining the treadmill of the taller subject, and inclining the treadmill of the shorter subject. For individuals

that frequently demonstrate spontaneous synchronization under normal conditions it was hypothesized that the mechanical properties of gait are preferentially tuned. For these individuals, any change to the interpersonal locomotor dynamics would result in a decrease in synchronization.

METHODS

Subjects

A convenience sample of 24 pairs of subjects was recruited from the local student population ($n=48$, $\text{age}=22.69\pm 1.86$ years, $\text{mass}=67.16\pm 6.35\text{kg}$). All subjects were free of neurological or musculoskeletal conditions that might affect gait. Institutional Review Board approval was obtained prior to data collection, and all subjects gave their informed consent prior to participation. In order to increase the number of pairings that demonstrate poor synchronization, efforts were made to pair individuals with large differences in leg length. Overall, mean leg length difference for the current study was $5.87\pm 4.41\text{cm}$, which is greater than that utilized in previous analyses of a similar nature (e.g. $4.00\pm 3.33\text{cm}$ (Nessler & Gilliland, 2009a)). All subjects were kept naïve to the purpose of the experiment until data collection had ended.

General Procedures

Each pair of subjects walked on a treadmill (Vision Fitness T9800S) for sixty seconds under fourteen different conditions. For all conditions, baseline walking speed was determined by finding the self-selected, preferred walking speed of each subject, and then calculating the mean for each subject pairing. The first condition required each subject to walk independent of

their partner (i.e. SOLO condition) at this baseline walking speed (Fig 1). For the second trial, subjects walked side-by-side at the same speed with both treadmills level (i.e. PAIRED condition, Fig 1). For trials 3-6, the treadmill speed of one subject was held at baseline while the other treadmill speed was increased by 0.2mph (0.32km/h) and 0.4mph (0.64km/h), respectively, for both participants (2 speed combinations x 2 subjects). For the eight remaining trials, treadmill slope remained level for one subject, while the other treadmill was both inclined and then declined at 3° and 6° (4 combinations of treadmill slope x 2 subjects, Fig 1). For all inclined and declined trials, the speed of both treadmills was set to the baseline walking speed. Trials were presented in a pseudorandom fashion; incremental increases in slope or speed were presented in a consistent pattern (e.g. the 0.4mph increase in treadmill speed was always presented following the 0.2mph increase in speed for a particular subject), but sets of treadmill speed trials, decline trials, and incline trials were presented in random order (e.g. some pairings performed 4 speed trials first, while others performed 4 decline trials, etc.).

Incremental increases in treadmill slope (i.e. 3° and 6° or approximately 5% and 10% grade) were selected to be consistent with previous analyses of sloped walking (Leroux, et al., 2002; McIntosh, et al., 2005). Treadmill inclination (positive slope, or uphill) was achieved using the adjustable gradient feature of the treadmill. Consistent treadmill decline (negative slope, or downhill) was achieved by placing custom fabricated aluminum blocks under the rear feet of the treadmill (Fig 1). Each block was designed to ensure both treadmill stability and precision in treadmill angle relative to the laboratory floor. Incremental increases in treadmill speed (i.e. 0.2 and 0.4mph, or 0.32 and 0.64km/h) were selected based upon the results of a brief pilot experiment.

Subjects stepped on side by side treadmills with the instrument panel and hand rails removed to limit obstruction of cameras and to ensure that subjects retained full peripheral vision of their partner. In order to simulate walking in a casual environment, no restrictions were given with regard to conversation or the direction of subjects' gaze. A six camera Vicon MX3 motion capture system was used to record data at 120 Hz from markers placed over each subject's right lateral malleolus. Additional MATLAB routines were then used to evaluate synchronization (reported here as the percentage of the trial in which subjects matched step frequency) and certain aspects of step kinematics (step length and stride time). A conservative estimate of test-retest reliability using data from previous experiments (Nessler & Gilliland, 2009a) suggest that this measure of synchronization is consistent within subject pairings (ICC=0.96).

Data Analysis

Synchronization was evaluated using a method that has been described previously (Nessler & Gilliland, 2009a). Briefly, this process involves calculation of the average step frequency for each subject using a moving 5 second window across the entire trial. Frequency locking was defined for a particular data point if the difference in step frequency was less than 0.02Hz between subjects. The percentage of synchronization was then calculated as the number of data points per trial in which frequency locking occurred divided by the total number of data points in the trial.

Comparison of synchronization under varying treadmill conditions was then carried out under the following assumption. Previous study has demonstrated that certain subject pairings

will consistently synchronize spontaneously when treadmill speed and slope are equal, while others will consistently remain un-synchronized under the same conditions (Nessler, et al., 2009b; Nessler & Gilliland, 2009a). Simulation results and previous data also suggest that this difference may be related to interpersonal differences in the mechanical properties of gait (Nessler, 2009c; Nessler & Gilliland, 2009a). Therefore, it was hypothesized that interpersonal mechanics of gait are likely near optimal (i.e. sufficiently matched) for pairings that demonstrate a high degree of entrainment during the PAIRED trial. Changes to treadmill speed and/or slope in these pairings would likely result in a decrease in synchronization. In this case, the mechanical properties of gait would be altered, presumably in a manner that reduces their similarity. Conversely, subject pairings that do not demonstrate synchronization during the PAIRED trial likely stand to benefit most from alterations in treadmill speed and slope, as these adjustments may act to reduce interpersonal differences in the mechanics of gait.

Under this assumption, pairings were classified as either good synchronizers (i.e. SYNC group) or as poor synchronizers (i.e. NonSYNC group) by comparing synchronization during the PAIRED trial to a cutoff level of 50% that was established through an off-line, subjective analysis of the data. This cutoff level is represented in Figure 2, which also demonstrates that there was a clear and distinct difference between pairings that synchronized during this trial and pairings that did not, similar to results that have been reported previously (Nessler & Gilliland, 2009a). This approach was utilized because to date, the factors that contribute to synchronization remain unclear. In the absence of a method of classification supported by physiological mechanisms, this approach provides a measure of face-validity as a clear delineation of synchronization appeared across subject pairings. Within each pairing, subjects

were identified as either the tall or short partner, and each trial was therefore referred to as an alteration to either the taller or shorter person's treadmill (e.g. taller+0.2mph).

Statistical analysis of synchronization data began with a total of six repeated measures ANOVA; three separate ANOVA for the speed, incline, and decline trials for each of the two groups (SYNC and NonSYNC). Each repeated measures ANOVA was performed across five trials: two trials involving manipulations to the shorter person's treadmill, the PAIRED trial, and two trials involving manipulations to the taller person's treadmill (e.g for the Speed trials: Shorter+0.4mph, Shorter+0.2mph, PAIRED, Taller+0.2mph, Taller+0.4mph). Because synchronization data were not normally distributed, all raw percentages were transformed using the natural logarithm prior to statistical analysis. Statistical significance was determined with respect to family-size alpha level set to 0.05, and the Bonferroni correction technique was used to offset statistical bias arising from multiple comparisons. Significant results for each repeated measures ANOVA were followed up post hoc with separate, paired t-tests, comparing performance during each altered condition with that of the PAIRED condition to determine which conditions resulted in significant changes in spontaneous synchronization.

Statistical analysis of stride length and stride time involved two additional repeated measures ANOVA across the same 5 conditions. All subjects were combined for these analyses (n=48), and significant results were followed up post hoc with separate, paired t-tests. All post hoc comparisons were made with respect to each subject's SOLO walking condition and utilized the Bonferroni correction technique for multiple comparisons.

Analysis of the Interpersonal Effect

The underlying premise of this study is that changes to the mechanical properties of gait might enhance spontaneous synchronization of stepping between two individuals walking on side by side treadmills. However, previous study suggests that spontaneous synchronization of stepping arises as a result of multiple factors, of which the mechanical properties of gait are only one consideration (Nessler & Gilliland, 2009a; Oullier, et al., 2008; Richardson, et al., 2007; Richardson, et al., 2005b). In order to explore the idea that spontaneous synchronization of stepping is a true interpersonal effect involving additional factors (e.g. cognitive, social, behavioral, etc.), data from the PAIRED and SOLO trials were compared for members of the SYNC group using paired t-test. Each pairing completed two SOLO conditions; one for each subject walking by themselves. Here, the two SOLO conditions were analyzed to find how often subjects in a pairing walked with the same cadence (i.e. frequency locked), even though they weren't walking simultaneously. If synchronization was merely the consequence of the mechanical properties of walking, subjects would presumably match cadences to a similar degree during both the SOLO and PAIRED trials, as the mechanical properties were the same for both conditions.

RESULTS

Analysis of synchronization during the PAIRED trials revealed that half of the pairings (n=12) clearly fell into the SYNC group, and half of the pairings (n=12) clearly fell into the NonSYNC group (mean synchronization $81.17 \pm 16.36\%$ vs. $4.32 \pm 8.13\%$, $p < 0.001$, Fig 2).

When data for both the SYNC and NonSYNC groups were combined, the overall amount of

synchronization during the PAIRED trial ($44.6 \pm 41.13\%$) was lower than that typically seen for the case where pairings are randomized (Nessler, et al., 2009b; Nessler & Gilliland, 2009a), likely the result of attempts to combine subjects with differing leg lengths. Overall, leg length differences between the SYNC and NonSYNC groups were not statistically different ($5.18 \pm 4.31\text{cm}$ vs. $6.56 \pm 4.59\text{cm}$, respectively). Comparison of synchronization between the PAIRED and SOLO conditions for the SYNC group revealed that synchronization was significantly increased with the physical presence of a partner as opposed to simply matching the mechanical properties for each pairing ($81.17 \pm 16.36\%$ vs. $6.11 \pm 11.76\%$, $p < 0.001$, Fig 3).

For the SYNC group, the maxima of synchronization occurred during the PAIRED trial. Altering treadmill conditions in any way resulted in a decrease in synchronization (Fig 4). For example, increasing the treadmill speed of *either* the taller or shorter individual resulted in a significant decrease in synchronization when compared to the PAIRED trial ($12.54 \pm 29.05\%$ and $40.28 \pm 37.53\%$ vs. $81.17 \pm 16.36\%$ for the shorter+0.4mph and taller+0.4mph trials respectively, $p < 0.001$). In addition, mean synchronization decreased significantly for conditions in which the taller person's treadmill was inclined ($20.73 \pm 24.73\%$, $p < 0.001$) and for conditions in which the shorter person's treadmill was declined ($13.58 \pm 29.93\%$, $p < 0.001$).

For the NonSYNC group, spontaneous synchronization was significantly increased with respect to the PAIRED condition when the speed of the taller person's treadmill was increased ($4.32 \pm 8.13\%$ vs. $54.65 \pm 46.24\%$, $p = 0.006$) and when the shorter subject's treadmill was inclined ($4.32 \pm 8.13\%$ vs. $33.40 \pm 40.01\%$, $p = 0.006$, Fig 5). Similar to the SYNC group, synchronization was also significantly reduced for conditions in which the speed of the shorter person's treadmill was increased ($0.08 \pm 0.06\%$ $p = 0.012$).

Adjustments in treadmill speed and inclination also resulted in significant changes in stride length and stride time (Table 1). When compared to the SOLO walking condition, increasing the speed of each subject's treadmill resulted in a significant increase in stride length ($1.28\pm 0.10\text{m}$ vs. $1.36\pm 0.08\text{m}$, $p<0.001$) and decrease in stride interval ($1.17\pm 0.08\text{sec}$ vs. $1.12\pm 0.08\text{sec}$, $p<0.001$). Declining each subject's treadmill resulted in a significant decrease in both stride length ($1.21\pm 0.12\text{m}$, $p<0.001$) and stride interval ($1.13\pm 0.08\text{sec}$, $p<0.001$). Finally, inclining each subject's treadmill resulted in a significant increase in both stride length ($1.36\pm 0.1\text{m}$, $p<0.001$) and stride interval ($1.21\pm 0.1\text{ sec}$, $p<0.001$). Altering the slope and speed of the treadmill of each subject's partner did not result in any significant changes to the first subject's stride length or stride interval. In addition, stride length and stride interval were consistently very similar for both the SOLO and PAIRED conditions.

An important assumption to the current analysis held that interpersonal mechanics of gait were within a preferentially tuned "region" for a particular pairing during trials in which synchronization was observed to be greatest. Therefore, a best performance scenario was found for each pairing by identifying the walking trial in which the greatest amount of spontaneous synchronization occurred, from among the 13 trials performed (SOLO trial excluded). When each of these best performances was taken, regardless of the trial in which it occurred, average synchronization was found to be $85.02\pm 28.41\%$ across all subjects (SYNC and NonSYNC combined). Under normal conditions (i.e. PAIRED), the average synchronization was found to be $44.60\pm 41.30\%$ across all subjects ($p<0.001$, Fig 6).

DISCUSSION

There were four primary results to this study. First, altering the speed and inclination of one person's treadmill has a significant effect on the occurrence of spontaneous synchronization of stepping with a second individual on an adjacent treadmill. Second, these results demonstrate that spontaneous synchronization is not simply the result of matching the mechanical properties of partners; additional factors must also be at work to facilitate this behavior. Third, there appears to be a region of biomechanical congruency that is related in part to subject leg length, treadmill speed, and treadmill slope. Proper "tuning" of these biomechanical properties can increase spontaneous synchronization in subjects that would otherwise demonstrate very little entrainment. When data for all subjects (SYNC and NonSYNC groups) were examined together, improved tuning of these properties demonstrated the potential to increase synchronization from approximately 45% to 85% (Fig. 6). Finally, altering the speed and slope of an individual's treadmill affects stride length and stride interval in a manner that is consistent with simulation results and previous study (Leroux, et al., 2002; McIntosh, et al., 2005). Because stride length and stride interval vary in a predictable manner, these trends can be used to inform the selection of proper inter-subject treadmill settings. Overall, these results suggest that spontaneous synchronization can be promoted in the laboratory or clinic, thereby improving the utility of this technique for gait rehabilitation and facilitating further study of this behavior.

The connection between the passive dynamics of gait and step synchronization is relatively straightforward: increasing the length of an inverted double pendulum increases the period of oscillation. On average, individuals with greater leg length will take longer strides with an increased stride time. When two individuals with differing leg lengths are paired, it is

likely that the individual with the longer legs will prefer to take larger and slower steps than those of their partner. If such differences are great enough to preclude spontaneous synchronization, then measures that either decrease the stride time of the taller subject or increase the stride time of the shorter subject would likely increase the probability of synchronization. The current analysis demonstrates that this idea holds true for humans on side by side treadmills. For the NonSYNC group, synchronization was significantly increased when the speed of the taller person's treadmill was increased or when the shorter person's treadmill was inclined. The kinematic data demonstrate that each of these situations resulted in either a decrease in stride interval for the taller subject or an increase in stride interval for the shorter subject, consistent with the behavior of an inverted double pendulum.

Certain pairs of subjects will spontaneously entrain while others will not. The current data (Fig 2), as well as data from previous analyses, demonstrate a relatively strict dichotomy across pairings (Nessler, et al., 2009b; Nessler & Gilliland, 2009a; van Ulzen, et al., 2008; Zivotofsky & Hausdorff, 2007). While the current data provide some insight to the mechanical factors that underlie spontaneous synchronization, they are not sufficient to completely explain this behavior. For example, it is reasonable to conclude from the current data that the interpersonal mechanics of gait were sufficiently tuned to cause synchronization for all of the pairs in the SYNC group during the PAIRED trial. If the mechanical properties manipulated in the current study were the only factors responsible for this behavior, then pairings from the SYNC group would likely walk with the same cadence for both the SOLO and PAIRED trials, and synchronization would be similar for both conditions (i.e. side by side vs. the case where independent walking trials were combined to make the Non-PAIRED condition). However, the

results indicate that though the mechanical properties of gait were identical for both conditions, synchronization was significantly reduced when these individuals did not walk simultaneously ($81.17 \pm 16.36\%$ vs. $4.32 \pm 8.13\%$, $p < 0.001$).

This result suggests that additional factors should be considered in the study of this behavior. For example, previous investigators have demonstrated that interpersonal synchronization during multiple activities in humans is related to the social dynamics among participants (Issartel, et al., 2007; Oullier, et al., 2008; Richardson, et al., 2007; Richardson, et al., 2005a). Such influences have been known to persist for a period of time following interaction between individuals and should be considered in interpretation of these data. In particular, the current experiment did not control for each subject's familiarity with their partner, and variations in this relationship may also explain some of the variation in synchronization. Other possible influences on this behavior include the potential for dominant vs passive roles in this interaction, activation of the mirror neuron system and its role in spontaneous synchronization (Cochin, et al., 1999; Kohler, et al., 2002; Rizzolatti & Craighero, 2004), as well as speaking during side by side walking to allow for synchronization of breathing and speech.

Finally, little is known regarding the passive control mechanisms that guide spontaneous synchronization. The present data, as well as previous investigation (Nessler, et al., 2009b; Nessler & Gilliland, 2009a; van Ulzen, et al., 2008; Zivotofsky & Hausdorff, 2007), suggest that the presence of one's partner generates a type of behavioral attractor for bipedal stepping. The current results also suggest that the consistency and reliability of this attractor is greatest when the passive dynamic properties of gait, such as leg length and relative treadmill speed and slope, are preferentially tuned. The robustness of this behavioral attractor with respect to changes in

these passive dynamics might therefore be evaluated by locating the region in which these mechanical properties can vary while still promoting spontaneous synchronization. For example, the present data demonstrate that spontaneous synchronization remained at or above 60% in the SYNC group when the speed of the taller person's treadmill was increased by 0.2mph (0.32km/h) or the speed of the shorter person's treadmill was increased by approximately 0.1mph (0.16km/h, Fig 4). These values might be interpreted as a type of mechanical limit for this behavior, and future investigation may help to establish normative limits for these mechanical properties. Knowledge of such limits might be used to study gait pathology by comparing the strength or robustness of this attractor across patient populations. In addition, a greater understanding of the mechanical limits of this behavior would be useful for studying the influence of other environmental cues on human locomotion, such as mechanical foot bridge oscillations (Strogatz, et al., 2005), auditory stimuli (Hausdorff, et al., 2007; Roerdink, et al., 2007; Roerdink, et al., 2009; Thaut, et al., 1996), or social dynamics (Issartel, et al., 2007; Oullier, et al., 2008; Richardson, et al., 2007; Richardson, et al., 2005a).

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TABLE 1. Mean Values for Select Measures of Step Kinematics Under Varying Conditions of Treadmill Dynamics for All Subjects (n=48)

	Solo	Paired	+0.4 mph (+0.64 km/h)	+ 6° Incline	- 6° Decline
Stride Length [m]	1.28±0.09	1.28±0.10	1.36±0.08 [†]	1.36±0.10 [†]	1.21±0.12 [†]
Stride Interval [sec]	1.17±0.08	1.17±0.09	1.12±0.08 [†]	1.21±0.10 [†]	1.13±0.08 [†]

Values are mean ± SD

[†]*differs significantly from Paired condition (p<0.001 for all cases)*

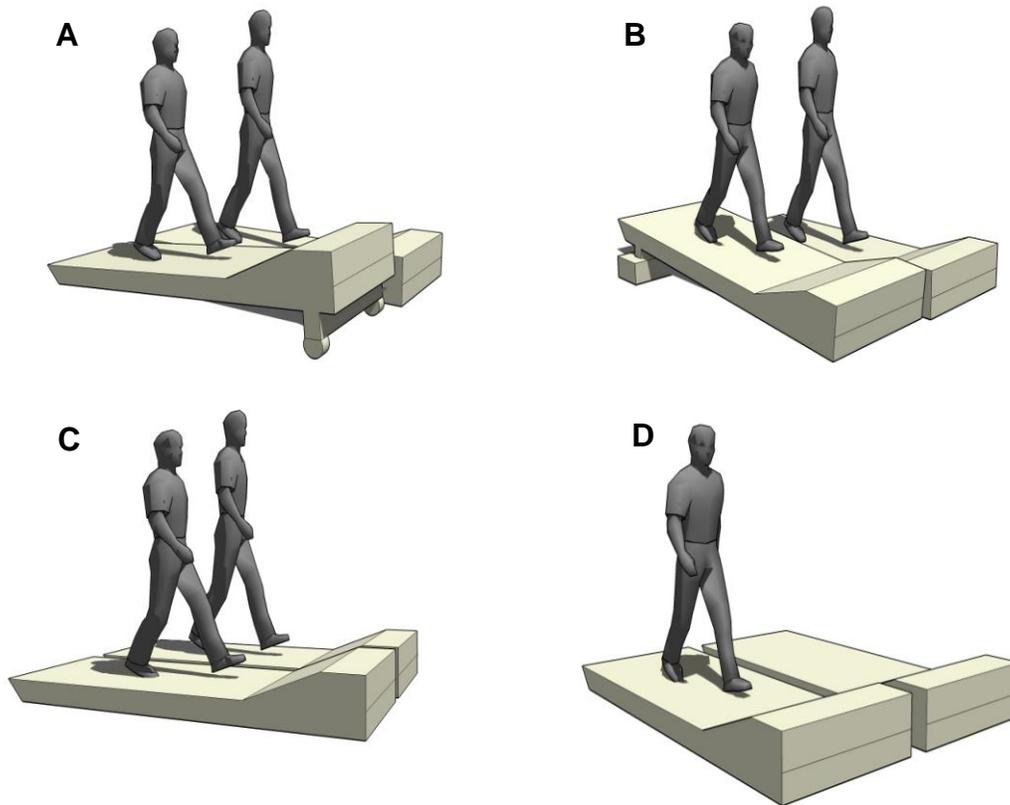


Fig 1 – Illustration of select side by side walking protocols. **A)** Shorter subject's treadmill inclined at 6° with both subjects walking at the baseline walking speed for this pairing (i.e. S +6). **B)** Shorter subject's treadmill declined at 6° with both subjects walking at the baseline walking speed (i.e. S -6). **C) PAIRED** condition: both subjects walking at the baseline walking speed, both treadmills level, **D) SOLO**: shorter subject walking at baseline walking speed with level treadmill, without a partner.

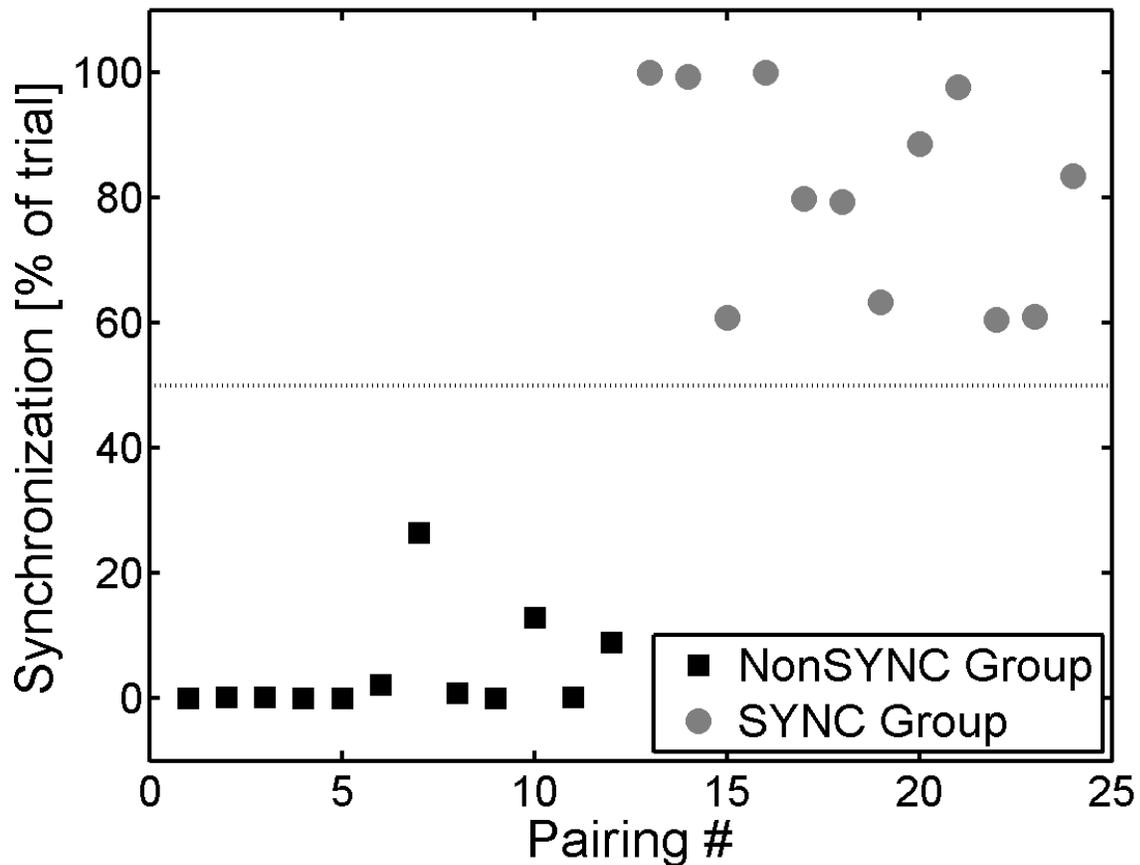


Fig 2 – Spontaneous synchronization for individual pairings (n=24) during the **PAIRED** trial (i.e. treadmills level with equal speed). Pairings that demonstrated a high level of spontaneous synchronization (i.e. greater than 50% of the trial) were classified as part of the **SYNC** group, and pairs that didn't synchronize (i.e. less than 50% of the trial) were classified as part of the **NonSYNC** group. All pairings analyzed clearly fell into one of the two categories.

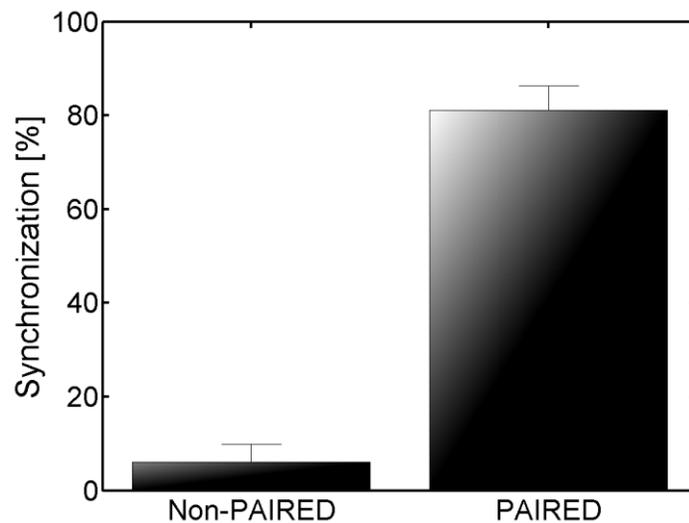


Fig 3 – Spontaneous synchronization was significantly increased during the **PAIRED** walking condition for members of the **SYNC** group ($p < 0.001$). **Non-PAIRED**: amount of synchronization that was found by combining the **SOLO** (independent) walking trials from each pairing in the SYNC group. **PAIRED**: walking on side by side treadmills at the same speed with no inclination. **Non-PAIRED** synchronization represents an estimate of the amount of synchronization that might be expected simply because certain mechanical properties of walking are matched for both partners, absent of factors related to the neurophysiological, social, and behavioral factors related to side by side walking. Bars represent standard error of the mean.

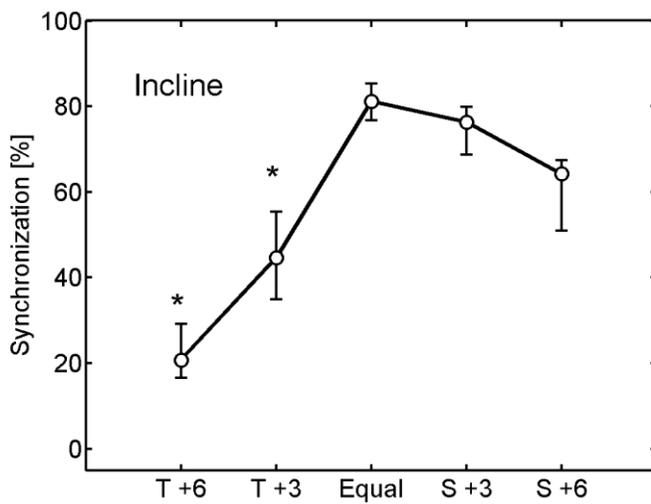
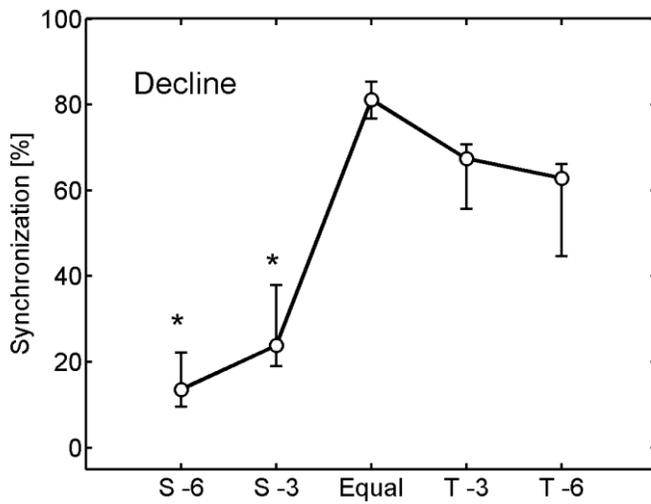
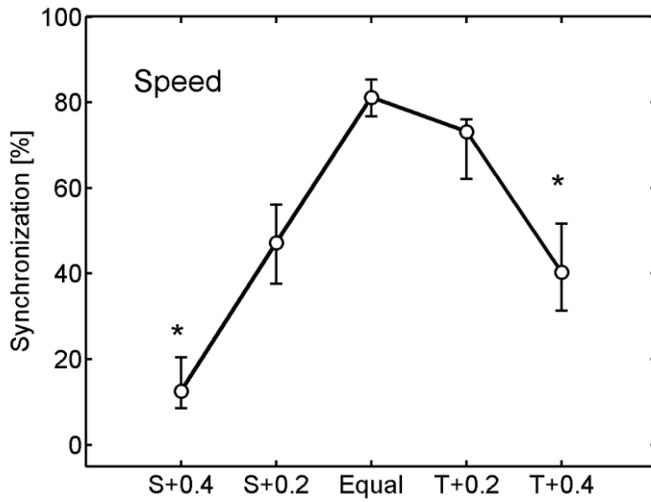


Fig 4 – Synchronization results for subject pairs that were classified as the **SYNC** group (12 pairs, n=24) under conditions of varying speed and treadmill slope. For the speed condition, ± 0.2 & 0.4 are mph (± 0.32 & 0.64 km/h), for the incline and decline conditions, ± 3 & 6 are treadmill slope in degrees. **S**: shorter subject, **T**: taller subject. Synchronization was defined as the percent of the trial in which pairings matched stride frequency. Statistical analyses were performed on log-transformed data but data depicted here are not transformed. *denotes conditions for which synchronization was significantly different from the **PAIRED** condition in which treadmill speed and slope were equal. Changes in spontaneous synchronization resulting from varying speed and treadmill slope exhibited strong correlation across the 3 types of treadmill conditions: $r=0.74$ (Incline vs. Speed), $r=0.82$ (Decline vs. Speed), and $r=0.98$ (Incline vs. Decline). Bars represent median absolute deviation and are calculated separately for data above and below the median to adjust for non-normality.

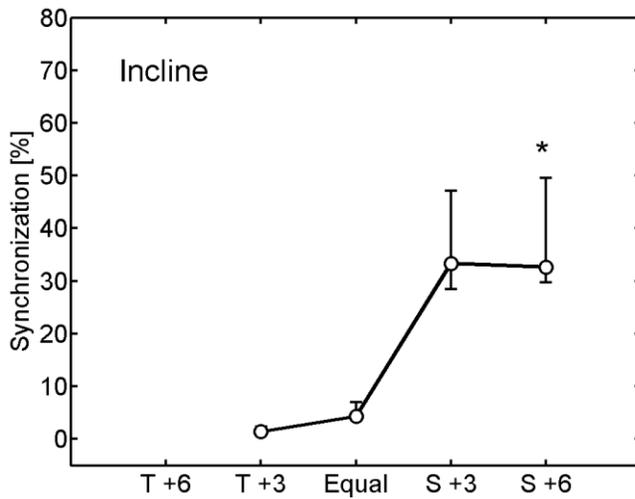
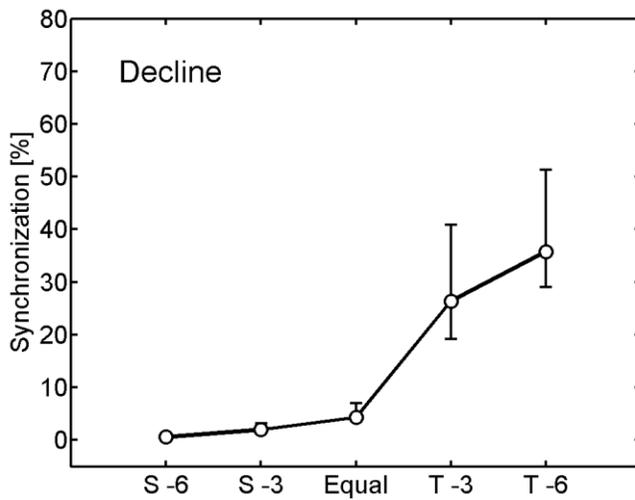
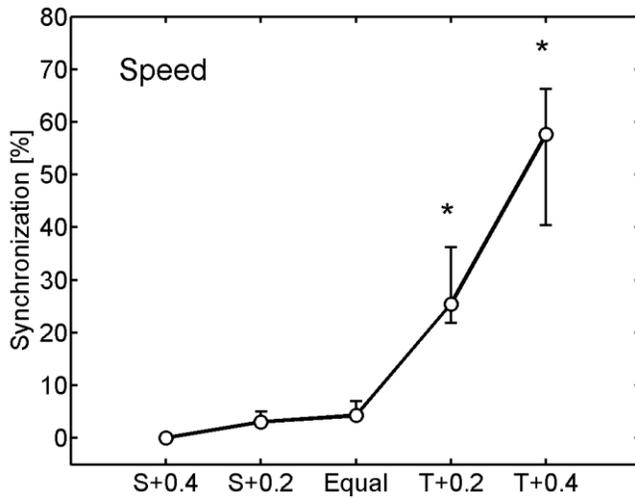


Fig 5 – Synchronization results for subject pairs that were classified as the **NonSYNC** group (12 pairs, n=24) under conditions of varying speed and treadmill slope. For the speed condition, ± 0.2 & 0.4 are mph (± 0.32 & 0.64 km/h), for the incline and decline conditions, ± 3 & 6 are treadmill slope in degrees. **S**: shorter subject, **T**: taller subject. Synchronization was defined as the percent of the trial in which pairings matched stride frequency. Statistical analyses were performed on log-transformed data but data depicted here are not transformed. *denotes conditions for which synchronization was significantly different from the **PAIRED** condition in which treadmill speed and slope were equal. Changes in spontaneous synchronization resulting from varying speed and treadmill slope exhibited strong correlation across the 3 types of treadmill conditions: $r=0.95$ (Incline vs. Speed), $r=0.99$ (Decline vs Speed), and $r=0.97$ (Incline vs. Decline). Bars represent median absolute deviation and are calculated separately for data above and below the median to adjust for non-normality.

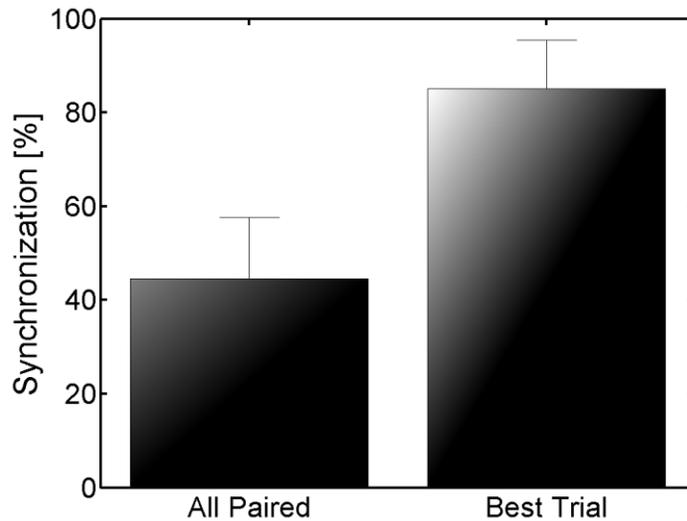


Fig 6 – Comparison of spontaneous synchronization for 2 walking conditions across all subjects (both SYNC and NonSYNC groups). **All PAIRED:** mean synchronization for all pairs (n=24) during the PAIRED walking condition in which both treadmills had the same speed and slope, **Best Trial:** mean synchronization across all pairs utilizing only the condition in which the greatest amount of synchronization occurred (i.e. preferentially tuned mechanics properties of gait). The trial from which this value was taken varied across subject pairings. Bars represent standard error of the mean.