# Information about task duration influences energetic cost during split-belt adaptation and retention of walking patterns post-adaptation

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# Abstract

Studies of locomotor adaptation have shown that adaptation can occur in short bouts and can continue for long bouts or across days. Information about task duration might influence the adaptation of gait features, given that task duration influences the time available to explore and adapt the aspects of gait that reduce energy cost. We hypothesized that information about task duration influences adaptation to split-belt walking based on two competing mechanisms: individuals anticipating a prolonged adaptation period may either (1) extend exploration of energetically suboptimal gait patterns, or (2) adapt toward a more energy-efficient pattern earlier to maintain an energetic reserve to sustain the task longer. We tested three groups: N=19 participants received minute-by-minute updates during a 10-minute adaptation duration (True group), N=19 participants received no updates during a 10-minute adaptation duration and were misled to expect a prolonged 30-minute adaptation duration (False group), and N=14 participants received one update halfway through a 10-minute adaptation duration (Control group). We measured step length asymmetry, leg work, and metabolic cost. Our results partially supported our hypothesis but did not confirm the underlying mechanisms. While step length asymmetry did not differ significantly between groups during adaptation, the True group generated a more effortful gait pattern with a greater increase in metabolic cost (p=0.002) and higher work with the leg on the slow belt (p=0.012). Additionally, the True group showed no association between step length asymmetry and metabolic cost (p=0.203), contrary to the Control (r=-0.55, p=0.043) and False groups (r=-0.51, p=0.027). Finally, we observed that the False group showed greater retention of the split-belt aftereffects than the Control and False groups (p<0.001). Thus, adapted locomotor and energetic patterns are influenced by information about task duration, indicating that Information about task duration should be controlled for, or can be manipulated to elicit different efforts during adaptation.

# Introduction

Humans continuously adapt locomotor patterns in response to environmental conditions, such as changes in walking terrain, footwear, and load carriage [1–3]. In laboratory settings, split-belt treadmills have been used to study locomotor adaptation, where individuals walk on a treadmill with two separate belts (one for the right limb and one for the left limb) that can be independently controlled to move at different speeds [4,5]. Split-belt walking leads to immediate changes in intralimb coordination and gradual changes in interlimb coordination [5], which are attributed to distinct neural control mechanisms [5,6]. A vast amount of literature has shown that the neuromotor system can adapt to the split-belt's asymmetric environment and retain some of the adaptive changes in locomotion in the short and long term [5,7–10]. The kinematic, kinetic, and physiological changes that occur during short locomotor adaptation bouts of 10-15 minutes [11–21], during long adaptation bouts of 45 minutes [22], or during split-belt adaptation across multiple days [23] have been characterized; it is well established that individuals adapt from walking with asymmetric step lengths toward more symmetric step lengths, reduce positive work by the legs, and reduce metabolic cost during adaptation. However, it is not yet known whether these adapted gait patterns are influenced by the information about different adaptation durations.

Empirical [24–26], and simulation studies [27,28] have shown that different cost functions are optimized at different points in the adaptation process: the early stages of locomotor adaptation are associated with the regulation of dynamic balance control, whereas the later stages of locomotor adaptation are associated with reductions in energetic cost. A recent study reported that during a 20-minute split-belt walking protocol, measures of balance adapted in less than a minute, whereas metabolic cost and mechanical work adapted in ~4-6 minutes [25]. Our previous work showed that even after 45 minutes of continuous split-belt walking, individuals

78    continued to adapt their gait pattern and achieve additional reductions in mechanical work and

79    metabolic energy cost [22]. We also estimated from this prolonged adaptation bout that it takes

80    around 1600 strides or close to 30 minutes to adapt step length asymmetry completely [22].

81    Adaptation has also been studied using exoskeletons [29–33]. A previous study assessing

82    adaptation to an ankle exoskeleton showed that muscle activation patterns adapted faster than

83    step frequency, and that the variability in step frequencies and muscle activation patterns

84    decreased during adaptation [31]. This higher variability when first exposed to a novel locomotor

85    adaptation task is thought to correspond to exploration of different aspects of the walking

86    pattern to identify strategies that support energetic cost reduction [31,32]. Similarly, other

87    studies using exoskeletons showed different timescales of adaptation to different exoskeleton

88    parameters [29]. Thus, given that multiple domains of locomotor adaptation change over

89    different timescales, we propose that task duration will impact the way people adapt to a novel

90    locomotor task.

91

92    Since energetic cost is optimized during the later stages of adaptation, information about a

93    longer task duration might influence the adaptation of the aspects of gait underlying this

94    energetic cost reduction. As individuals adapt their walking pattern to the split-belt treadmill,

95    they reduce step length asymmetry, positive mechanical power, and positive mechanical work

96    generated by their legs [11,19,20,22,24,25], which is associated with a reduction in metabolic

97    cost [11,22]. In fact, studies have shown that walking patterns can change continuously, over

98    different timescales, even for small energetic savings [32–34].  Here, we pose that information

99    about task duration may influence the time course of adaptation of different aspects of gait that

100   reduce energy cost.

101

102   The main goal of our study was to determine if information about task duration affects the

103   adaptation of locomotor patterns. We tested the hypothesis that individuals provided with

104    minute-by-minute information of a 10-minute adaptation duration (True group – True task

105    duration information) will have a different adapted locomotor pattern with different metabolic

106    cost than those individuals who were informed that they will sustain a locomotor adaptation task

107    for a prolonged time of 30 minutes but who will actually sustain it for 10 minutes (False group –

108    False task duration information). We compared our two experimental groups to a Control group,

109    that received true information about task duration before the start of the adaptation trial, but

110    without the minute-by-minute updates. Two contrasting mechanisms can explain this metabolic

111    and locomotor pattern differential: Mechanism 1) given that the split-belt task is only of

112    moderate intensity, the False group might spend more time exploring suboptimal locomotor

113    patterns as they prepare to sustain the task for longer, whereas the True group will aim to reach

114    a less costly pattern within the allotted time; if mechanism 1 drives adaptation, we hypothesize

115    that the False group will show les adaptation of step length asymmetry, higher metabolic cost,

116    and more work by the legs compared to the True and Control groups. Mechanism 2) The False

117    group might adapt toward a generally less costly pattern than the True group to be able to

118    maintain an energetic reserve needed to sustain the task longer [35–37]; if mechanism 2 drives

119    adaptation, we hypothesize that the False group will show greater adaptation, lower metabolic

120    cost, and less work by the legs compared to the True and Control groups. Since our previous

121    work showed that adaptation duration influences the duration but not the magnitude of the

122    aftereffects during post-adaptation [22], and all groups will adapt for the same duration, we

123    hypothesize that the locomotor pattern during post-adaptation will not differ between groups. A

124    better understanding of how information about task duration influences adaptive processes is

125    vital in the design of training schedules aimed at retraining walking behaviors as part of

126    rehabilitation interventions [38,39] or via the use of assistive devices [29,33,40,41].

127

## Materials and Methods

Since our hypothesis is based on differences in metabolic cost, we assessed the effect size of detecting a difference in metabolic cost after 10 minutes of adaptation. We obtained metabolic cost measures in N=15 individuals from a previous study that assessed split-belt adaptation duration of 45 minutes [22]. We extracted data during split-belt walking between minutes 1-2 (early adaptation) and 9-10 (late adaptation in the experimental protocol used here). We obtained the mean and standard deviation of the metabolic cost at these points to calculate the effect size needed to detect a reduction in metabolic cost for 10 minutes of adaptation. These data provided an effect size of 0.76. With a sample of 16 individuals in the True and False groups, we would have a power of 0.82 to detect a reduction in metabolic cost.

To assess differences in the True group and the False group relative to the locomotor pattern described in typical adaptation studies, we also collected a Control group post-hoc, which, like previous work, was informed about a 10-minute task duration at the beginning of the split-belt adaptation trial and only received one update halfway during adaptation. We collected a Control group of N=14 participants, with a sample size similar to previous studies that showed a reduction in energetic cost and mechanical work during adaptation (Buurke et al. 2018 N=14; Finley et al. 2013 N=11; Selgrade et al. 2017a N=14). This group also allowed us to ensure that any potential differences in our True and False groups are due to the misinformation in the False group or minute-by-minute information of task duration in the True group.

Participants between the ages of 18-35 were recruited for this study. Participants were excluded if they had a history of lower extremity surgery or if they had any lower extremity injury such as a fracture or sprain in the last two years, performed more than 10 hours of weekly exercise, reported current cough, cold, congestion, or any respiratory ailment that affected breathing, had

153    previous experience walking on a split-belt treadmill, or had a history of neurological disorders

154    or severe head trauma. The Chapman University Institutional Review Board approved all

155    experimental procedures, with approval number IRB-23-189, and participants provided written

156    informed consent before testing. All study aspects conformed to the principles described in the

157    Declaration of Helsinki.

158

159    Data were collected at the Gait Behavior Lab at Chapman University's Department of Physical

160    Therapy using a Gait Real-time Analysis Interactive Lab (GRAIL) system (Motek Medical

161    Base.V., Houten, Netherlands). The GRAIL is equipped with 10 motion capture cameras (Vicon

162    Motion Systems Ltd, Oxford, UK), and an instrumented dual-belt treadmill (Motek Medical

163    Base.V). We used a metabolic cart to measure energetic expenditure (TrueOne 2400,

164    Parvomedics, Salt Lake City, UT, USA). Participants were instructed not to eat or have caffeine

165    at least two hours before the experiment. Before each experiment, we calibrated the motion

166    capture system and the metabolic cart per the manufacturer's specifications. During all walking

167    trials, participants wore a harness to prevent falls, without providing body weight support.

168    Participants did not hold on to a handrail at any point in the experiment.


169    ## Experimental Protocol


170    After informed consent, participants were fitted with a mask covering their nose and mouth to

171    measure their breathing (Fig. 1A). First, participants' resting caloric expenditure was measured

172    while standing for six minutes. Then, participants underwent three walking trials with breaks

173    between each trial until metabolic cost reached standing baseline levels to ensure resting

174    conditions before continuing. The first trial, Baseline (Base), had participants walking for six

175    minutes with the belts under each leg moving at 1.0 m/s. The second trial (Split) had

176    participants walking for 10 minutes with the left belt moving at 1.5 m/s (fast) and the right belt at

177    0.5 m/s (slow) (Fig. 1B, C). We chose 10 minutes of split-belt adaptation as this duration allows

178    us to observe adaptation of spatiotemporal gait measures [5], metabolic cost [11,42], and work

179    by the legs [19]. Participants were assigned to either the True or False groups via a coin flip to

180    ensure randomization. The True group participants performed the split-belt adaptation trial with

181    true information of how long the trial would last, and they were given an update on the time

182    remaining every minute. The False group participants were given the misleading instruction

183    verbatim: "You will be walking until we obtain the data needed, which can take about 30

184    minutes". Participants in the False group were not given updates on time elapsed or time

185    remaining, and they also walked for 10 minutes. At the end of the $10^{th}$ minute, we stopped the

186    treadmill and told participants that we had collected all the necessary data. Participants in the

187    Control group were informed that the task would last 10 minutes and only given an update

188    halfway that they had five minutes remaining. The final trial (Post-adaptation) had participants

189    walking again during a post-adaptation trial for 6 minutes with the belts under each leg moving

190    at 1.0 m/s. All participants received the same instructions for the post-adaptation trial, indicating

191    that this was the final trial and that it would last six minutes.

192

193    **Fig 1. Experimental setup and protocol.** A) Experimental setup showing experimental

194    groups, metabolic mask, and marker location to calculate spatiotemporal variables. From

195    top to bottom, the groups are the Control group (red), the True detailed time information

196    group (green), and the False time information group (blue). B) Split-belt configuration.

197    For all participants, the left belt was set at 1.5 m/s and the right belt at 0.5 m/s. 52

198    participants reported the right leg as the leg they would use to kick a ball. C)

199    Experimental protocol. Bars indicate each belt, and numbers indicate belt speed. Bar

200    width indicates the duration of each experimental condition. Participants reported their

201    rate of perceived exertion during the time points identified by the arrows. S: Standing. B:

202    Baseline. EA: Early adaptation. MA: Mid-adaptation. LA: Late adaptation. EP: Early post-

203    adaptation. LP: Late post-adaptation. GTRO: Greater Trochanter. LEPI: Lateral

204    Epicondyle. LMAL: Lateral Malleolus.

205

206    Participants were asked to rate their level of exertion via the modified Borg Rating of Perceived

207    Exertion (RPE) (Borg, 1962) using their fingers, since they were wearing the metabolic mask, to

208    indicate on a scale of 1-10 which level of the RPE table they perceived. During the Base trial,

209    participants reported RPE at the five minute mark. During the Split trial, they were asked to rate

210    their level of exertion at the one (early adaptation – EA), five (mid-adaptation – MA), and nine

211    minute (late adaptation – LA) marks. During the tied post-adaptation trial, participants rated their

212    RPE at the one (early post-adaptation – EP) and five minute marks (late post-adaptation – LP)

213    (Fig. 1C).

## Data Acquisition

215    We recorded marker data to calculate spatiotemporal variables and force data to calculate work

216    by the legs. The positions of reflective markers located bilaterally on the greater trochanter,

217    lateral epicondyle of the femur, and lateral malleolus were recorded at 100 Hz (Fig.1A). Force

218    plates embedded into the split-belt treadmill recorded the ground reaction forces generated by

219    each leg with a sampling frequency of 1000 Hz. Metabolic cost was recorded by determining the

220    rates of oxygen consumption ($VO_2$) and carbon dioxide production ($VCO_2$). We also collected

221    heart rate (HR) as a measure of cardiovascular intensity using a Polar H10 chest strap monitor

222    (Polar Electro Inc., Bethpage, NY, USA), synchronized to the metabolic cart.

## Data Processing and Analysis

224    We used custom-written code in MATLAB R2023b (Mathworks, Natick, MA, USA) for all data

225    processing and analyses as in previous work [22,34]. We estimated the energy consumed using

226     the standard Brockway equation to obtain metabolic rate [43]. We subtracted each participant's

227     standing metabolic rate from each walking trial. Thus, all metabolic rate values presented here

228     are net metabolic rates. A fourth-order low-pass digital Butterworth filter smoothed marker data

229     and ground reaction force data using cut-off frequencies of 10 Hz and 20 Hz, respectively. We

230     calculated step lengths using marker data, defined as the distance between the lateral malleoli

231     markers at the instance of peak anterior position of the respective marker. Step length

232     asymmetry was then defined as follows:

233     $$SLA = \frac{SL_{fast} - SL_{slow}}{SL_{fast} + SL_{slow}}$$     1

234     With $SL_{fast}$ representing the step length at heel strike of the fast leg, and $SL_{slow}$ representing

235     the step length at heel strike of the slow leg. We calculated leading and trailing limb placement

236     for each limb as the fore-aft distance of the ankle markers relative to the midpoint between

237     markers placed bilaterally on the greater trochanters.

238

239     We estimated the mechanical work performed by the legs using an extension of the individual

240     limbs method [19,20,22,34,44,45]. This method approximates the legs as massless pistons and

241     the entire body as a point mass. We measured individual leg ground reaction forces from the

242     instrumented treadmill, and segmented forces into strides using a vertical ground reaction force

243     threshold of 32 N [19] to identify the beginning and end of each stride. We calculated the

244     mediolateral, fore-aft, and vertical center of mass velocities by integrating the center of mass

245     accelerations. We then calculated mechanical power as the dot product between the center of

246     mass velocity and the ground reaction force from each leg. To determine the total positive and

247     negative work performed by a leg or a belt, we calculated the time integral of the positive or

248     negative portion of the mechanical power over the stride cycle. Work was normalized by leg

249     length and mass to derive unitless mechanical work. We calculated leg length as the distance

250     between the greater trochanter markers and the ground during standing.

251

252     We derived variability during adaptation as in a previous study [31]. We determined the

253     variability by applying a high-pass filter with a cut-off frequency of 0.033 steps$^{-1}$, and then

254     calculated the standard deviation of this filtered signal during the initial, middle, and final minute

255     of the trial. The variability was expressed as a normalized value relative to Base variability. We

256     assessed variability in variables that represent different constructs of adaptation: step length

257     asymmetry, which is used to track adaptation, net work due to its relationship to metabolic cost,

258     and step width as a proxy for balance.

259


## Statistical Analyses

261     Statistical analyses were run in R version 4.2.2 and MATLAB R2023b. We assessed data for

262     normality using the Shapiro-Wilk test. We compared age, height, and weight between the three

263     experimental groups using one-way ANOVA or Kruskal-Wallis tests for not normally distributed

264     data.

265

266     We obtained average values for step length asymmetry, step lengths, step width, and positive

267     and negative work for each leg for the last five strides of the Base trial. For EA, MA, and LA we

268     averaged the first, middle, and last five strides of the Split trial [26]. For the Post trial, we

269     averaged the first five and last five strides (EP, LP, respectively). These are close to the time

270     points when we obtained RPE and average measures of metabolic cost.

271

272     The metabolic power for the Base condition was computed by averaging the power for the last

273     two minutes. The metabolic power for EA, MA, and LA was averaged between the second and

274     third minutes, the fifth and sixth minutes, and the ninth and tenth minutes, respectively, of the

275    Split condition to match the RPE reporting periods (Figure 1C). We used the second instead of

276    the first minute for metabolic data as the average duration to reach peak metabolic power is

277    around one minute [11,46]. Finally, the metabolic power for the Post-adaptation condition was

278    averaged between the second and third minutes and the fifth and sixth minutes of this condition

279    to obtain average values of metabolic cost for EP and LP, respectively.

280

281    We tested differences during the Base condition between groups using linear models with group

282    (Control, True, False) as a categorical predictor and all outcome variables as a continuous

283    response, to assess if there are baseline differences between groups that could have influenced

284    our results. As the goal of our analysis was to observe differences within the Split and Post-

285    adaptation conditions between groups, we ran separate models for these conditions. For the

286    Split condition, we used linear models with time (EA, MA and LA) and group (Control, True,

287    False) as categorical variables. We also included the value for the respective outcome

288    measured during Base as a covariate, and its interaction with group and time, given that we

289    observed that the response during the adaptation task depended on baseline walking

290    characteristics. For the Post-adaptation condition, we used linear models with time (EP and LP)

291    and group (Control, True, False) as categorical variables. We also included the value for the

292    respective outcomes measured during Base as a covariate and its interaction with group and

293    time. The models had the general form of:

294         $$x_{Split/Post} \sim Group * Time + x_{Base} * Time + x_{Base} * Group$$         2

295    where $x$ is the scaled value measured during either the split-belt task or post-adaptation for any

296    of the following outcomes: metabolic cost, step length asymmetry, step width, positive and

297    negative work by each leg. Results for heart rate and rating of perceived exertion, step lengths,

298    and step times are included in the Supplementary Materials. The reference level for the linear

299    models for group was set as Control group, and for time was set as EA for the split-belt models

300    and EP for the post-adaptation models. We assessed residual plots for each model to ensure

301    that they were normally distributed. Post-hoc comparisons were corrected via the false

302    discovery rate. We also assessed individual correlations between metabolic cost, work, step

303    length asymmetry and step lengths between groups. To allow comparison of correlation

304    coefficients for different sample sizes, we used a Fisher transformation of the resulting

305    correlation coefficients.

306

307    To assess differences in variability, which we use here to quantify exploration, we used a linear

308    model of the form:

309    $$variability_{x\ Split/Post} \sim Group * Time \qquad\qquad 3$$

310    Where $x$ is either step length asymmetry, step width or net work. Since the variability data were

311    normalized to Base, we did not use Base as a covariate. The reference level for this model was

312    the Control group during EA.

313

# Results

315    N = 52 participants volunteered for this study: Control group - N=14, True group - N=19, False

316    group - N=19. No significant differences were observed in participant demographics between

317    groups (Table 1). Metabolic cost and kinematic data were collected for all participants. Heart

318    rate data was missing in six participants due to Bluetooth connectivity issues (three in the

319    Control group, one in the True group, and two in the False group). Force data was collected

320    from all participants except one in the False group, for whom force data were corrupted, which

321    hindered performing mechanical calculations. Data for all participants, as available, were

322    included in all analyses.

323

324    **Table 1**

| Group | Control | True | False | |
|---|---|---|---|---|
| N | 14 | 19 | 19 | |
| Age (yrs) | 23.2 ± 3.4 | 24.8 ± 3.4 | 25.7 ± 4.7 | p=0.191 |
| Height (cm) | 170 ± 10 | 167 ± 8.2 | 167 ± 9.2 | p=0.446 |
| Weight (kg) | 70.2 ± 12.9 | 73.0 ± 13.1 | 67.6 ± 13.6 | p=0.458 |

325 Table 1: Participant demographics for both experimental groups are reported as mean ±

326 standard deviation. P-values for one way ANOVA and for Chi-Square tests show no differences

327 in group demographics.

328

329 We did not observe significant differences in any of our outcome variables between groups

330 during the Base condition that could have influenced the Split or Post-adaptation results

331 (p>0.352, Table 2).

332

333 **Table 2**

| Group | Control | True | False | |
|---|---|---|---|---|
| Metabolic Cost (W) | 2.26 ± 0.51 | 2.47 ± 0.42 | 2.43 ± 0.51 | p= 0.487 |
| Heart Rate (bpm) | 100 ± 14 | 100 ± 12 | 94 ± 12 | p=0.352 |
| RPE | 2.0 ± 0.75 | 1.75 ± 1.0 | 2.0 ± 0.92 | p=0.675 |
| Step Length Left (mm) | 514 ± 36 | 509 ± 28 | 511 ± 24 | p=0.900 |
| Step Length Right (mm) | 509 ± 46 | 500 ± 24 | 508 ± 29 | p=0.682 |

334

335 Table 2: Biomechanical and physiological characteristics for participants in the three groups

336 during the Base trial walking with belts tied at 1.0 m/s. Data are reported as means ± standard

337 deviation. P-values for linear models using group as a categorical predictor. bpm: beats per

338 minute. RPE: rating of perceived exertion 1-10 scale.

## Information about task duration did not influence step length

## asymmetry during split-belt adaptation

341 We hypothesized different adaptation patterns between groups. The linear model assessing

342 step length asymmetry as a function of group, time and baseline asymmetry during split-belt

343 adaptation returned a significant intercept ($\beta_0$=-0.30, 95%CI [-0,36, -0.25], p<0.001), and a

344 significant main effect of time ($\beta_{TimeMA}$=0.24, 95%CI [0.16, 0.32], p<0.001 and $\beta_{TimeLA}$=0.28,

345    95%CI [0.20, 0.36], p<0.001) indicating a reduction in asymmetry during adaptation across

346    groups. We also observed an effect of the False group ($\beta_{GroupF}$=-0.08, 95%CI [-0.15, 0.01],

347    p=0.036), indicating that the False group was slightly more asymmetric but this more negative

348    asymmetry was offset by a marginal interaction between the False group and MA

349    ($\beta_{GroupF:TimeMA}$=0.09, 95%CI [-0.01, 0.20], p=0.072) and the False group and LA

350    ($\beta_{GroupF:TimeLA}$=0.10, 95%CI [-0.01, 0.20], p=0.068) (adjusted $R^2$=0.66) (Fig. 2A-B). Contrary to our

351    hypothesis, we observed a similar adaptation of step length asymmetry across groups.

352

353          **Fig 2. Step length asymmetry and step width during split-belt adaptation.** A) Step

354          length asymmetry timeseries during the split-belt walking between the control (Control –

355          red), true information about task duration (True – green), and false information of task

356          duration (False - blue) groups. Time windows indicating EA, MA, and LA are indicated in

357          the figure. B) Distribution of average step length asymmetry between groups during the

358          five strides corresponding to EA, MA, and LA. Across groups, asymmetry decreased

359          from EA to MA and LA. (p<0.001) C) Distribution of average step widths. No differences

360          over time or between groups were observed. Abbreviations as in Figures 1 and 2.

361

362    The linear model assessing step width as a function of group, time, and baseline asymmetry

363    during split-belt adaptation returned a significant intercept ($\beta_0$=281, 95%CI [267, 294], p<0.001)

364    and a significant effect of baseline step width ($\beta_0$=19, 95%CI [10, 28], p<0.001) but no effect of

365    group or time (Fig. 2C), indicating that individuals did not adapt step width (adjusted $R^2$=0.34).

366    We did not see differences between groups for fast and slow step lengths, swing times, and

367    limb placements (Supplementary Materials).

368

## Information about task duration influenced metabolic cost during split-belt adaptation

We hypothesized differences in metabolic cost between groups during adaptation. The linear model assessing metabolic cost as a function of group, time, and baseline cost during split-belt adaptation returned a significant intercept ($\beta_0$=3.30, 95%CI [3.04, 3.96], p<0.001), a significant main effect of baseline metabolic cost ($\beta_{Base}$=0.30, 95%CI [0.13, 30.48], p<0.001), and a significant main effect of LA ($\beta_{TimeLA}$=-0.39, 95%CI [-0.76, 0.03], p=0.035) indicating that across all groups, participants reduced cost from EA to LA. The model returned a significant interaction between the True group and baseline metabolic cost ($\beta_{GroupT:BaseMet}$=0.32, 95%CI [0.11, 0.52], p=0.002) (adjusted $R^2$=0.66). Estimated marginal trends of the slope between baseline metabolic cost with split-belt metabolic cost by groups show a greater slope in the True group compared to both the Control group (slope True = 1.27 vs slope Control = 0.62, p=0.007) and the False group (slope False = 0.84, p=0.044), indicating a greater increase in the True group's metabolic cost relative to baseline metabolic cost during split-belt adaptation (Fig. 3A-C). These results support our hypothesis of different costs between groups. However, these different costs were due to an increased rate of change from baseline metabolic cost in the True group, contrary to our two mechanistic hypotheses. Heart rate and RPE results are presented in the Supplementary Materials (Supplementary Figure 1).

**Fig 3. Metabolic cost, heart rate, and perception of effort during split-belt adaptation.** A) Net metabolic power timeseries during the split-belt walking between the control (Control – red), true information of task duration (True – green) and false information of task duration (False - blue) groups. Time windows indicating EA, MA, and LA are indicated in the figure. B) Slopes of the relationship between metabolic cost

393    during baseline and metabolic cost during EA, MA and LA. A significantly greater slope

394    was observed in the True group compared to both the Control and False groups

395    (adjusted p<0.050). C) Average metabolic cost during EA, MA, and LA. A significant

396    reduction in metabolic cost from EA to LA was observed across groups.  Other

397    abbreviations as in Figure 1 and Table 2.

398

## Information about task duration influenced positive work during split-belt adaptation

401  We hypothesized that less mechanical work would be performed in the less metabolically costly

402  group. The linear model assessing positive work by the fast leg as a function of group, time and

403  baseline work during split-belt adaptation returned a significant intercept ($\beta_0$=0.036, 95%CI

404  [0.032, 0.040], p<0.001), a significant main effect of baseline work by the fast leg ($\beta_{Base}$=0.005,

405  95%CI [0.002, 0.008], p<0.001), an effect of time ($\beta_{TimeMA}$=-0.011, 95%CI [-0.017, -0.006],

406  p<0.001 and $\beta_{TimeLA}$=-0.013, 95%CI [-0.018, -0.008], p<0.001) but no effect of group (adjusted

407  $R^2$=0.52). Contrary to our hypothesis, the model suggests that all individuals across groups

408  similarly reduced positive work by the fast leg during adaptation (Fig. 4A, C).

409

410    **Fig 4. Positive work by the fast and slow legs during split-belt adaptation.** A)

411    Timeseries of positive work by the fast leg. B) Timeseries of positive work by the slow

412    leg. C) Distribution of average positive work by the fast leg between groups during the

413    five strides corresponding to EA, MA, and LA. We observed a significant reduction in

414    work from EA to MA and LA across groups. D) Distribution of average positive work by

415    the right leg between groups during the five strides corresponding to EA, MA, and LA.

416            We observed significantly higher work in the True group (p=0.012). W$^+$: positive work.

417            Other abbreviations as in Figures 1 and 2.

418

419 The linear model assessing positive work by the slow leg as a function of group, time and

420 baseline work during split-belt adaptation returned a significant intercept ($\beta_0$=0.013, SE=0.0014,

421 p<0.001), a significant main effect of baseline work by the slow leg ($\beta_{Base}$=0.003, SE=0.0010,

422 p=0.010), and a significant main effect of True group ($\beta_T$=0.005, SE=0.0018, p=0.012). These

423 results indicate that positive work by the slow leg in the True group was significantly higher

424 during adaptation than in the Control and False groups (adjusted R$^2$=0.34) (Fig. 4B, D). Thus,

425 supporting our hypothesis, we observed differences in positive work by the slow leg between

426 groups, with the less costly groups (Control and False) generating less positive work. However,

427 consistent with the metabolic cost findings, this was due to increased positive work with the slow

428 leg in the True group. Results for negative work are presented in the Supplementary Materials

429 (Supplementary Figure 2).

430

## Information about the duration of split-belt adaptation influenced the association between biomechanical and metabolic changes

434 We found a significant association between the change in step length asymmetry and the

435 change in metabolic cost for the Control group (r=-0.55, Fisher transformed r=-0.61, p=0.043)

436 and for the False group (r=-0.51, Fisher transformed r=-0.56, p=0.027). We did not observe an

437 association between metabolic cost and asymmetry in the True group (r=-0.31, Fisher

438 transformed r=-0.32, p=0.203) (Fig. 5A).

439

440     **Fig 5. Associations between biomechanical and metabolic measures.** A)

441     Association between change in step length asymmetry and change in metabolic cost

442     from EA to LA. B) Association between change in positive work by the fast leg and

443     change in metabolic cost from EA to LA. C) Association between change in positive work

444     by the slow leg and change in metabolic cost from EA to LA. D) Association between

445     change in positive work by the fast leg and change in step lengths by the fast leg from

446     EA to LA. E) Association between change in positive work by the slow leg and change in

447     step lengths by the fast leg from EA to LA. Abbreviations as in Figures 1 and 2.

448

449

450   We found a significant association between the reduction in positive work by the fast leg and

451   change in metabolic cost for the False group (r=0.67, Fisher transformed r=0.81, p=0.002), but

452   not in the Control (r=0.50, Fisher transformed r=0.54, p=0.071) or True (r=0.41, Fisher

453   transformed r=0.44, p=0.079) groups (Fig. 5B). We did not find an association between the

454   reduction in positive work by the slow leg and change in metabolic cost (Fig. 5C).

455

456   We found a significant association between the change in step lengths of the fast and slow leg

457   and the change in positive work by the fast leg in the False group (r=-0.69, Fisher transformed

458   r=-0.83, p=0.002 for fast step lengths and r=0.55, Fisher transformed r=0.62, p=0.017, for the

459   slow leg) (Fig. 5D-E). We observed a significant association between the change in step lengths

460   of the fast leg and positive work by the fast leg in the True group (r=-0.77, Fisher transformed

461   r=-1.02, p<0.001) (Fig. 5D). We did not observe a significant association between the change in

462   step lengths and work in the Control group or change in slow step lengths and work in the True

463   group.

464

# Information about task duration influenced the exploration of walking patterns during adaptation

The linear model assessing variability in step length asymmetry as a function of group and time returned a significant intercept ($\beta_0$=4.66, 95%CI [3.51, 5.81], p<0.001), a significant effect of time ($\beta_{TimeMA}$=-2.52, 95%CI [-4.15, -0.89], p=0.003 and $\beta_{TimeLA}$=-2.51, 95%CI [-4.14, -0.88], p=0.003), a significant effect of group ($\beta_{GroupT}$=2.40, 95%CI [0.88, 3.91], p=0.002 and $\beta_{GroupF}$=2.73, 95%CI [1.22, 4.25], p<0.001) and a significant interaction between time and group ($\beta_{TimeLA:GroupT}$=-2.42, 95%CI [-4.57, -0.27], p=0.027, $\beta_{TimeMA:GroupT}$=-3.14, 95%CI [-5.29, -0.99], p=0.004, $\beta_{TimeLA:GroupT}$=-2.99, 95%CI [-5.13, -0.84], p=0.007) (adjusted $R^2$=0.49). Post-hoc comparisons indicated significantly higher variability, indicating more exploration in the True and False groups during EA compared to the Control group (p<0.005) (Fig. 6A). We did not observe differences between MA and LA in variability as a measure of exploration. Thus, both the True and False groups had more exploration during EA than the Control group, contrary to one of our mechanistic hypotheses that the False group might spend more time exploring suboptimal locomotor patterns. The linear models assessing variability in step widths, and net work identified a significant main effect only of time but not of group, indicating that variability in step width and work decreased from EA to MA and LA similarly across groups (Fig. 6B-C).


**Fig 6. Variability of gait features during adaptation.** A) We observed significant differences between groups in step length asymmetry variability during EA. Variability significantly decreased during MA and LA. No differences between groups were observed during MA and LA. B) Variability in step widths decreased over timepoints

488    across all groups. C) Variability in net work decreased over timepoints across all groups.

489    Abbreviations as in Figures 1 and 2.

490

## Information about task duration during split-belt adaptation influenced step length asymmetry during post-adaptation

493    We hypothesized no differences during post-adaptation between groups. The linear model

494    assessing step length asymmetry as a function of group, time and baseline asymmetry during

495    post-adaptation returned a significant intercept ($\beta_0$=0.24, 95%CI [0.20, 0.28], p<0.001), a

496    significant main effect of baseline asymmetry ($\beta_{Base}$=0.05, 95%CI [0.02, 0.08], p=0.003), a

497    significant main effect of LP ($\beta_{TimeLP}$=-0.22, 95%CI [-0.28, -0.16], p<0.001), a significant effect of

498    False group ($\beta_{GroupF}$=0.12, 95%CI [0.07, 0.18], p<0.001), a significant interaction between False

499    group and LP ($\beta_{GroupF:TimeLP}$=-0.11, 95%CI [-0.19, -0.03], p=0.006) and a significant interaction

500    between LP and baseline asymmetry ($\beta_{Base:TimeLP}$=-0.04, 95%CI [-0.07, -0.005], p=0.022)

501    (adjusted $R^2$=0.77). Overall, these results indicate a reduction in asymmetry from EP to LP for

502    all groups. Surprisingly, we found a higher asymmetry in the False group compared to the

503    Control (p<0.001) and True groups (p<0.001) during EP, indicating a greater after-effect of the

504    split-belt (Fig. 7 C-D). This contradicts our hypothesis that the post-adaptation locomotor pattern

505    would be similar between groups. The after-effect in the False group can be explained by

506    changes in the right leg, previously on the slow belt (Fig. 4-5). The linear model assessing right

507    step lengths as a function of group, time, and baseline step lengths during post-adaptation

508    returned a significant intercept ($\beta_0$=347, 95%CI [318, 376], p<0.001), a significant main effect of

509    baseline step lengths ($\beta_{Base}$=38, 95%CI [20, 56], p<0.001), a significant main effect of LP

510    ($\beta_{TimeLP}$=157, 95%CI [117, 198], p<0.001), a significant effect of the False group ($\beta_{GroupF}$=-70,

511    95%CI [-107, -32], p<0.001), and a significant interaction between the False group and LP

512    ($\beta_{GroupF:TimeLP}$=63, 95%CI [10, 116], p=0.043) (adjusted $R^2$=0.77). Overall, these results indicate

513    that step length on the right leg remains shorter during EP in the False group compared to the

514    Control group (p<0.001) and the True group (p<0.001) (Fig. 7E). No differences between groups

515    were observed for the left leg, which was previously on the fast belt. Results for metabolic cost

516    and work are included in the Supplementary Materials (Supplementary Figure 3).

517

518

519    **Fig 7. Step length asymmetry and work during post-adaptation.** A) Step length

520    asymmetry timeseries. B) Average step length asymmetry during EP, and LP.

521    Participants in the False group had a greater asymmetry during EP compared to the

522    Control and True groups (p<0.001). C) Average step lengths by the right leg during EP,

523    and LP. Participants in the False group had a shorter step length with the right leg during

524    EP compared to the Control and True groups (p<0.001). Abbreviations as in Figures 1

525    and 2.

526

527

528

# Discussion

530    Studies of motor adaptation have shown that adaptation begins within the first minute and

531    continues even after 45 minutes of adaptation to split-belt walking [22–25,29,31,47]. Information

532    about task duration might influence the adaptation of gait features to reduce energy cost, which

533    is considered to be the cost function in the later stages of adaptation [22,27,28,33]. Here, we

534    manipulated the information about task duration during split-belt walking adaptation in

535    neurotypical young adults. Our results partially supported our hypotheses: while we found

536     differences in adaptation between individuals who knew about a short task duration compared

537     to those who planned to adapt for 30 minutes, the mechanisms underlying these differences

538     contradict our hypotheses. We found that individuals who had detailed, true information about

539     task duration (True group) had a greater increase in metabolic cost from baseline, generated

540     more positive work with the slow leg and less negative work with the fast leg compared to

541     individuals who did not have detailed information about task duration (Control and False

542     groups). The biomechanical strategies adopted in the True group are the opposite of what has

543     been previously reported to reduce energetic cost during split-belt walking [22,34]. These results

544     support the idea that information about task duration influences the adaptation of walking

545     patterns towards patterns with different energetic costs.

546

547     We observed a strong relationship between gait biomechanics and energetic cost in individuals

548     who believed they would sustain the task longer (False group), supporting our second

549     mechanistic hypothesis that individuals may adapt toward a lower cost to maintain an energetic

550     reserve [35]. Surprisingly, the biomechanical strategies that supported this energetic reduction

551     differed from those we hypothesized. We originally expected to see more positive asymmetries

552     due to longer steps with the fast leg, which also allows for more negative work and less positive

553     work by the fast leg [22,34]. We found that the reduction in metabolic cost in the False group

554     correlated with step length asymmetry [22], but this correlation stemmed from changes in the

555     step lengths of the slow leg, not the fast leg. Specifically, the shortening of the slow step length

556     during adaptation was proportional to the reduction in metabolic cost. This is an interesting

557     finding since linear models indicated that, at the group level, there was no change in the slow

558     leg's step lengths from EA to LA. It might be the case that the slow leg adjustments are

559     heterogeneous across individuals, such that there is no group-level effect. Adjustments in step

560     length with the slow leg, rather than the fast leg, may result in a smaller energetic penalty [31],

561     and could supplement other adjustments previously reported [22]. Based on this discussion, we

562    assessed the changes in step lengths; we observed that both the change in slow leg step length

563    (r=0.55, p=0.017) and the change in fast leg step length (r=-0.68, p=0.002) were correlated with

564    the change in positive work by the fast leg in the False group, but not in the Control and True

565    groups, supporting the idea that the added slow leg adjustments aim at reducing work during

566    adaptation.

567

568    Our results assessing the exploration of walking patterns were surprising. We observed greater

569    variability in step length asymmetry upon initial split belt exposure in the True and False groups

570    compared to the Control group (Figure 6A). However, this occurred only for step length

571    asymmetry and not for step width or work, indicating that there might be another difference in

572    participant characteristics that potentially influenced these findings. Similar to previous literature

573    [31], we found reductions in variability indicating reductions in exploration across different

574    domains from EA to MA and LA. However, between groups, we found that from MA to LA

575    variability was not different between groups, indicating both similar duration and magnitude of

576    exploration of step length asymmetry over the 10 minutes of adaptation. Thus, our results

577    indicate that information about a longer or shorter task duration did not influence exploration of

578    walking patterns systematically.

579

580    Based on our results, a question regarding the True group arises: What cost function was

581    prioritized during split-belt adaptation? Studies have shown that other cost functions can be

582    prioritized over metabolic costs, such as muscle activations [48], comfort [49], time [50], or

583    balance [51]. Since the speed of the belts and the trial duration are fixed, no strategy would

584    reduce task duration as in other studies [50,52,53]. Another potential explanation relates to the

585    anticipatory regulatory model in physiology, which states that the central nervous system

586    modulates muscle recruitment and power generation based on expected exercise duration

587    [35,36], with muscle recruitment and power generation directly influencing energetic

588    consumption [54,55]. The idea of an anticipatory regulatory model is supported by a common

589    phenomenon observed in exercise known as the end spurt, where effort generation decreases

590    over time but increases when individuals are informed that the end of the task is approaching

591    [56,57]. An example of this anticipatory regulation can be seen when cyclists increase power

592    generation as the distance to the endpoint decreases [58,59]. Furthermore, if the distance to the

593    endpoint is unknown, cyclists will maintain lower power generation than when these same

594    participants knew the distance to the endpoint [59]. In another study on runners, individuals who

595    believed they would run for longer had lower perceived exertion throughout the task compared

596    to those who were informed of a shorter task duration [59]. While we also did not observe a

597    clear end spurt [56], we saw increased work of the slow leg throughout adaptation, which might

598    indicate that the entire 10-minute task was performed as the end spurt due to the short task

599    duration and moderate effort of the split-belt task. Another alternative explanation is that the

600    cost functions in the True group are the same, mainly balance and energetic cost, but the time

601    during adaptation, where each cost function shapes the gait pattern, differs from what has been

602    previously reported [25,28]. Based on our step width results as a proxy for balance (Fig. 2C),

603    while not significant, there appears to be a visually apparent difference in step widths among

604    participants in the True group, with participants in this group showing wider steps than those in

605    the Control and False groups. Thus, it could be the case that for a short time duration and

606    detailed task information, energetic cost becomes less of a priority, and other cost functions are

607    optimized over a longer timescale.

608

609    Another key and surprising finding of our study is that information about task duration influenced

610    the aftereffect of the split-belt walking pattern. Previous work has shown that split-belt

611    aftereffects during post-adaptation can vary in different pathological populations [60–62], when

612    adapting through gradual adjustments of the belt speeds and a longer adaptation time [63], or

613    when using visual feedback [15]. Here, we found that individuals who received false information

614     about a longer task duration experienced a greater aftereffect when the belts returned to moving

615     at the same speed. This aftereffect was measured as a more positive step length asymmetry

616     during EP, due to the step lengths on the right leg remaining shorter in the False group

617     compared to the Control and True groups. These shorter steps on the right leg were consistent

618     with the strategy that supported energetic cost reduction during split-belt walking in the False

619     group. Two potential mechanisms might explain this aftereffect. On one hand, the increased

620     aftereffect in the False group might indicate an initial selection of a previously experienced more

621     optimal gait pattern, supporting the idea that individuals select these patterns even for small

622     energetic savings [32]. On the other hand, it may be that the False group, who not only received

623     false information at the beginning of the task but also received no updates during the split-belt

624     task, adapted in a more implicit manner, as less awareness was directed to the task compared

625     to the True and Control groups; known to increase retention and transfer of the adapted gait

626     pattern [63,64].

627

628     Our study has several limitations. First, we did not systematically assess fitness levels across

629     participants. While our criteria excluded people who, at the time of the experiment, exercised

630     more than 10 hours per week, we did not exclude sedentary participants or those with a prior

631     history of participation in high-performance sports. As such, we cannot determine if either group

632     had different levels of fitness, which has been shown to affect energetic expenditure [65] and

633     adaptation [24]. This seems to be the case for the Control group, which exhibited a lower level

634     of metabolic cost during split-belt adaptation. We controlled for these differences in our

635     statistical analyses by using baseline costs as a covariate. Previous research has shown that

636     the amount of mechanical work reduction during adaptation is influenced by the timing of work

637     generation during the pendular phase of gait [19,20]. Our study did not assess whether our

638     experimental manipulation affected this pendular work generation. The different contexts

639     created by the various types of instructions in each group may have led to differences in

640   autonomic responses. While we measured heart rate, we were unable to obtain measures of

641   heart rate variability to determine sympathetic activation during the task in each group, which

642   could explain differences in heart rate and metabolic cost responses [66]. Finally, we used step

643   width as a proxy for balance since our marker set did not allow for the assessment of more

644   sensitive measures of balance during adaptation, such as extrapolated center of mass [25,42]

645   or whole body angular momentum [26,67], which may have hindered our ability to measure

646   additional balance adjustments in our protocol.

# Conclusion

648   Humans continuously adapt their locomotor patterns. Adaptation of kinematics, kinetics, and

649   metabolic cost has been reported during split-belt walking protocols of varying durations.

650   However, it is still unknown whether these adapted gait patterns are influenced by different

651   adaptation durations. We manipulated information about task duration during split-belt walking

652   in young adults. We found that when individuals receive detailed information about a short task

653   duration, they perform the task in an effortful and energetically costly manner, and the changes

654   in energetic cost are not associated with changes in gait biomechanics. In contrast, the strength

655   of the association between changes in energetic cost and changes in biomechanics seems to

656   depend on uncertainty regarding task duration. We also found that information about longer task

657   duration led to greater aftereffects during post-adaptation, indicating that planning to sustain a

658   task for longer can influence the retention of walking patterns. The simplest implication of our

659   findings is that adapted locomotor and energetic patterns are influenced by information about

660   task duration; as such, task duration information should be controlled and clarified during

661   experimental paradigms of motor adaptation. Our findings also imply that information about task

662   duration can be manipulated to elicit different efforts and varying retention of adapted patterns,

663   which can have implications for movement interventions in patient populations, particularly

664    individuals with endurance limitations. Future studies should investigate how feedback about

665    task duration influences adaptation, effort generation, and retention of walking patterns in

666    pathological populations.

# Data Availability

668    A detailed R-markdown with statistical models and the data used for statistical analyses for this

669    manuscript are available at: DOI 10.17605/OSF.IO/AW6XK https://osf.io/aw6xk/

670    Raw data are available upon reasonable request to the corresponding author.

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678

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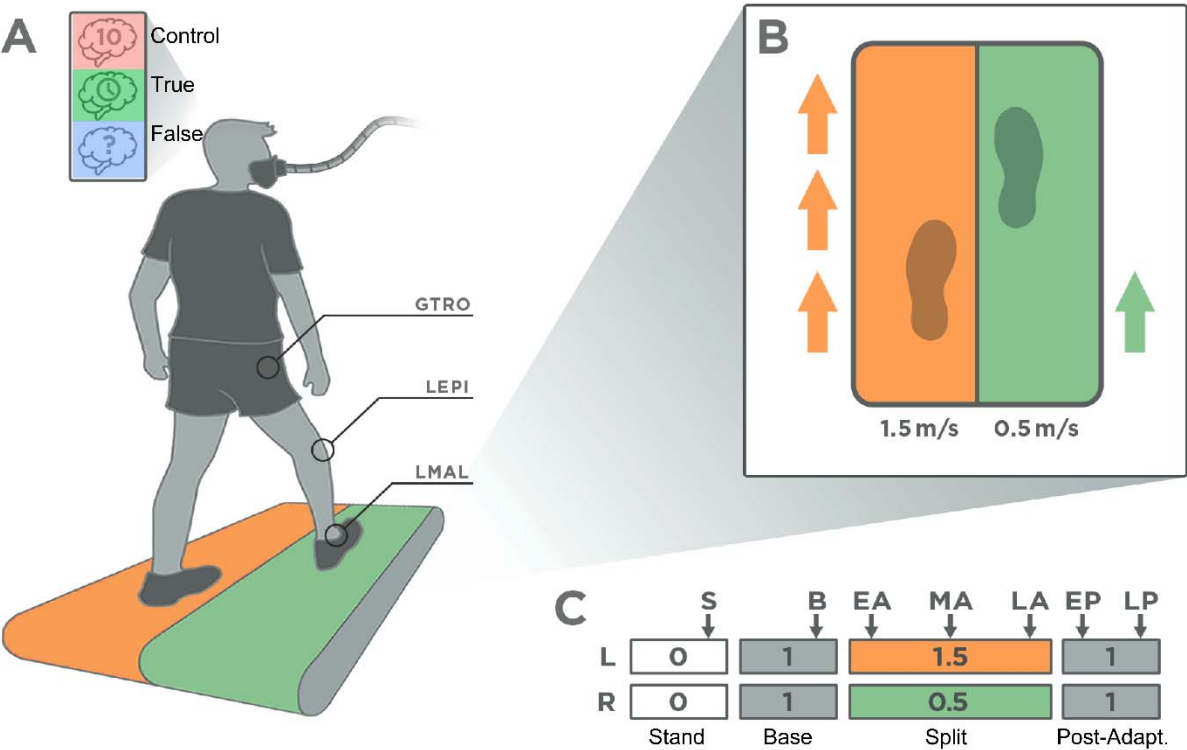
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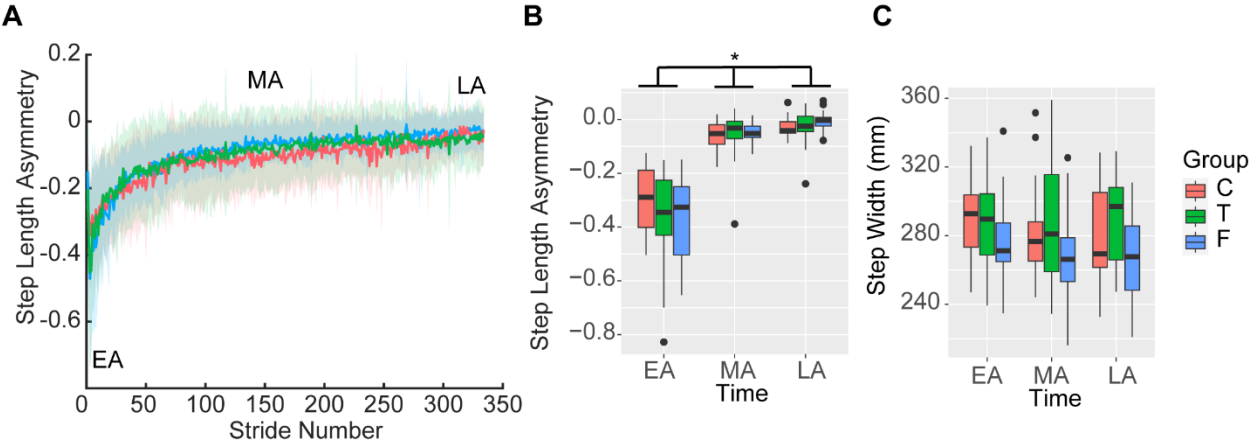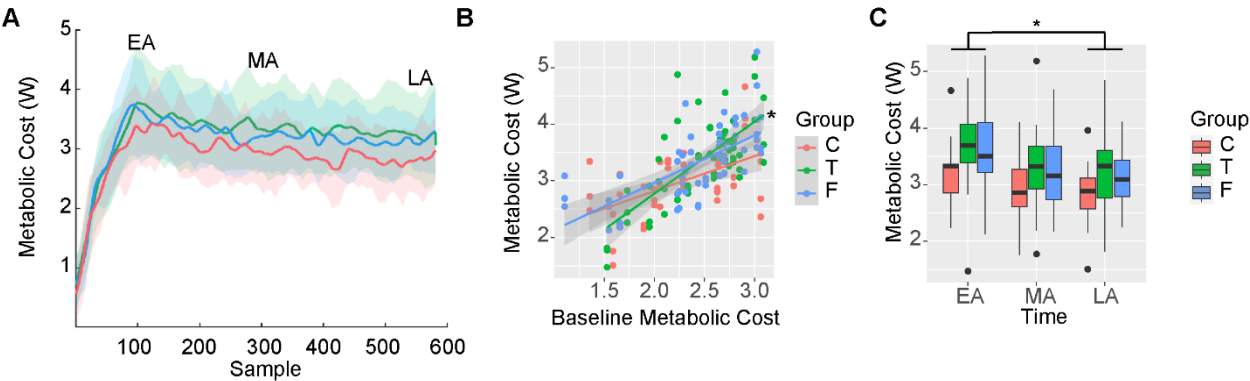873    **Figure 1.**

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879 **Figure 2.**



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882     **Figure 3.**



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886 **Figure 4.**



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890  **Figure 5**



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893 **Figure 6**



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896    **Figure 7**



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