Original Article

Anticipatory kinematics and muscle activity preceding transitions from level-ground walking to stair ascent and descent

Revised Manuscript Submitted to:

Journal of Biomechanics

December 2015

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Keywords: Biomechanics, ambulation, gait, electromyography, kinematics, stair transitions, anticipation

1 **Abstract**

2 The majority of fall-related accidents are during stair ambulation—occurring commonly at the top and
3 bottom stairs of each flight, locations in which individuals are transitioning to stairs. Little is known about how
4 individuals adjust their biomechanics in anticipation of walking-stair transitions.

5 We identified the anticipatory stride mechanics of nine able-bodied individuals as they approached
6 transitions from level ground walking to stair ascent and descent. Unlike prior investigations of stair
7 ambulation, we analyzed two consecutive “anticipation” strides preceding the transitions strides to stairs, and
8 tested a comprehensive set of kinematic and electromyographic (EMG) data from *both* the leading and trailing
9 legs. Subjects completed ten trials of baseline overground walking and ten trials of walking to stair ascent and
10 descent. Deviations relative to baseline were assessed.

11 Significant changes in mechanics and EMG occurred in the earliest anticipation strides analyzed for both
12 ascent and descent transitions. For stair *descent*, these changes were consistent with observed reductions in
13 walking speed, which occurred in all anticipation strides tested. For stair *ascent*, subjects maintained their speed
14 until the swing phase of the latest anticipation stride, and changes were found that would normally be observed
15 for decreasing speed.

16 Given the timing and nature of the observed changes, this study has implications for enhancing intent
17 recognition systems and evaluating fall-prone or disabled individuals, by testing their abilities to sense
18 upcoming transitions and decelerate during locomotion.

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1 **Introduction**

2 In urban environments, 40% of a person's daily walking tasks are non-steady, short-duration bouts of fewer
3 than 12 steps (Orendurff et al. 2008). Understanding how people transition between these bouts is important—
4 especially transitions that involve changing to a different mode of ambulation with altered mechanical
5 demands—as such transitions may increase the risk of falling and sustaining fall-related injuries.

6 The majority of fall-related accidents occur during stair ambulation (CDC 2010). Moreover, the three stairs
7 at the bottom and top of staircases, where individuals transition onto and from the stairs, respectively, are the
8 most common locations for missteps and falls (Sheldon 1960, Wild et al. 1981, Templer 1992). Transitions
9 from level ground to stairs are among the most challenging and hazardous tasks performed during community
10 living. This is especially true for individuals with physical limitations, including older adults (Lee and Chou
11 2007), stroke survivors (Laufer et al. 2000), and lower-limb amputees (Bae et al. 2009). Developing device or
12 rehabilitative interventions to improve outcomes for such individuals requires a comprehensive understanding
13 of how able-bodied individuals transition from level-ground walking to stairs.

14 To our knowledge, no study has investigated the anticipatory mechanics of able-bodied individuals during
15 the strides preceding transitions from level-ground walking to stairs. Although, studies have examined the
16 individual transition strides between walking and stairs. Yet, these studies were not focused on comprehensively
17 comparing mechanics and muscle activity (i.e., electromyography) (e.g., McFadyen and Carnahan 1997, Lee
18 and Chou 2006) or mechanics of the hip and knee in conjunction with the ankle (e.g., Gates 2004). More
19 commonly, the strides on the stairs following the transition strides (i.e., the stair strides) have been analyzed.
20 Other investigations have shown that step length parameters two strides preceding the transition to curbs
21 (Crosbie 1996) are modified in anticipation of the new surface. Given an assumed higher demand associated
22 with stairs, we expect similar and more substantial gait modifications may be identified prior to stair transitions.
23 Identifying these modifications would fill a knowledge gap and could allow for improved design of
24 rehabilitation protocols and assistive devices for individuals with disabilities.

25 The purpose of this study was to identify the anticipatory stride mechanics of able-bodied individuals as
26 they approach transitions from level ground walking to stair ascent and descent. We compared bilateral
27 kinematics of the hip, knee and ankle, center-of-mass kinematics, spatiotemporal stride characteristics as well as
28 electromyography (EMG) of muscles spanning the lower-limb. We hypothesized that significant changes in
29 these characteristics would be found in two anticipation strides of the leading and trailing limbs preceding
30 transitions to *both* stair ascent and descent. To transition to stair ascent and continue ambulating up stairs, a
31 person must increase their net mechanical energy (i.e., sum of kinetic and potential energies). This change could
32 occur during anticipation on level ground, when net changes in potential energy are zero. Thus, we further
33 hypothesized that the transitions to stair ascent would result in anticipatory mechanics and EMG that were
34 consistent with increasing the overall energetics of the body (i.e., increasing walking speed), while transitioning

to stair descent would result in anticipatory mechanics and EMG that were consistent with decreasing the overall energetics of the body (i.e., decreasing walking speed).

Methods

Protocol

Nine adults (4 males, 5 females) consented to the IRB approved protocol. All subjects reported no known pathologies, and were capable of ascending and descending a staircase without external assistance. Subjects completed ten trials of steady-state level walking, level walking to stair ascent and level walking to stair descent (Fig. 1). They were instructed to walk at their self-selected speed in all trials and conditions. Level walking occurred across a 10-m walkway. In the stair conditions, a custom built 4-step staircase was used, containing 7.5 inch risers and 12 inch treads (Fig. 1). Elevated platforms were placed adjacent to the stair case. In the stair conditions, subjects were asked to lead with a foot of their preference, and to maintain this convention across trials and conditions. The walkway preceding the staircase was 6.2 m and 5.2 m in length for ascent and descent conditions, respectively. These dimensions were constrained by the size of the gait lab.

Kinematics and electromyography

An 8-camera motion capture system (Motion Lab Systems, Inc.) was used to measure kinematics of the legs, pelvis and trunk (120 Hz). Forty reflective markers were placed bilaterally on the trunk, pelvis and lower-limbs (Fig. 1). In addition, markers were placed at the first, second, and fifth metatarsal heads on the outside of their shoes (Fig. 1). Joint and center-of-mass kinematics were calculated in Visual3D (C-Motion, Inc.).

Surface EMG were recorded at 1200 Hz (Delsys, Inc.), using a 500 Hz anti-aliasing low-pass hardware filter. Electrodes were placed bilaterally over 12 muscles including the gluteus maximus, gluteus medius, adductor magnus, semitendinosus, biceps femoris, rectus femoris, vastus lateralis, vastus medialis, tibialis anterior, gastrocnemius lateralis, gastrocnemius medialis, and soleus. EMG were band-pass filtered (40-450 Hz), and envelopes were created by applying a full wave rectification and a low-pass 5 Hz filter. For each muscle, smoothed EMG magnitudes were normalized to the maximum EMG value of the baseline walking condition.

Analyses

Data from baseline level-ground walking and two consecutive anticipation strides (Fig. 2) for both the leading and trailing legs, preceding the stair transition strides, were extracted. Mean values of each metric were computed over the stance and swing phase were as well as over 200 ms time windows preceding toe-off (terminal stance phase) and heel-strike (terminal swing). Paired t-tests were used to compare these metrics of each anticipation stride to the corresponding values from the same leg obtained during baseline level-ground walking trials. A Bonferroni correction was used to adjust the standard significance level to $\alpha/n=(0.05/3)$

1 =0.0167, since baseline level-ground walking and two anticipation strides were compared for each leg.
2 Spatiotemporal stride parameters were also compared in this manner.

3 **Results**

4 *Center-of-mass kinematics*

5 In anticipation strides preceding stair ascent, we observed no changes in the mean anterior translation or
6 velocity of the center-of-mass in stance (Fig. 3). We found a decreased center-of-mass velocity in the second
7 anticipation stride of the trailing leg in terminal swing and throughout swing (i.e., the latest portion of the latest
8 anticipation stride).

9 Changes in center-of-mass kinematics occurred earlier regarding stair descent. We observed a slower
10 velocity in terminal stance, throughout stance and throughout swing of the first anticipation stride of the leading
11 leg (i.e., the entirety of the earliest anticipation stride) (Fig. 3). Corresponding reductions in center-of-mass
12 translation were observed in the first anticipation stride of the leading leg. We also observed a significantly
13 slower velocity throughout stance of the first anticipation stride of the trailing leg; in terminal swing of the
14 second anticipation stride of the leading leg; and in terminal stance, terminal swing, and throughout swing of
15 the second anticipation stride of the trailing leg.

17 *Joint kinematics*

18 For stair ascent, we observed increased ankle dorsiflexion angle in the terminal stance of the first
19 anticipation stride of the leading leg (i.e., the earliest anticipation stride) (Fig. 3). Ankle dorsiflexion velocity in
20 terminal swing of the second anticipation stride of the leading leg decreased, as did hip flexion velocity in the
21 first and second anticipation strides of the leading leg (i.e., biased more extensor).

22 In contrast, anticipation strides for stair descent resulted in significant deviations from baseline condition in
23 both the leading and trailing legs (Fig. 3 and 4). Although no changes were observed in stance. Similar to stair
24 ascent, hip flexion velocity decreased during the first and second anticipation strides of the leading leg in
25 terminal swing (i.e., biased more extensor). In addition, hip flexion velocity was decreased in terminal swing of
26 the second anticipation stride of the trailing leg.

28 *Electromyography*

29 No changes in EMG were observed during terminal stance of anticipation strides before stair ascent (Figs. 5
30 and 6). During terminal swing, biceps femoris activity decreased in the second anticipation stride of the trailing
31 leg (i.e., the latest portion of the last anticipation stride) (Fig. 6). There were also changes in mean EMG
32 computed over the entire stance phase. These changes included decreased activity of the tibialis anterior, vastus
33 lateralis and semitendinosus in the first anticipation stride of the leading leg and also in the vastus lateralis

during the second anticipation stride of the leading leg (Fig. 5). Also, decreased adductor magnus activity over the stance phase was found in the first anticipation stride of the trailing leg (Fig. 6).

There were more widespread changes in EMG in the anticipation strides preceding stair descent. In terminal stance, soleus activity decreased in the first and second anticipation strides of the leading leg (Fig. 5), as well as in the second anticipation stride of the trailing leg (Fig. 6). Also in terminal stance, gastrocnemius medialis and lateralis activities decreased in the second anticipation strides of both the leading and trailing legs. In terminal swing, tibialis anterior activity decreased in the second anticipation stride of the trailing leg. Changes in EMG were also found when comparing mean values computed over the entire stance and swing phases. Tibialis anterior, soleus, gastrocnemius medialis and lateralis, vastus medialis and lateralis, rectus femoris, biceps femoris, semitendinosus, and gluteus maximus activities were decreased throughout the stance phase in the first anticipation stride of the leading leg (Fig. 5). Decreased activities of the soleus, vastus lateralis and rectus femoris in the second anticipation stride of the leading leg were also found over the stance phase, as well as of the biceps femoris over the swing phase in the second anticipation stride of the leading leg. In the first anticipation stride of the trailing leg, decreased activities computed over the stance phase were found in the soleus, vastus medialis, vastus lateralis and adductor magnus. In the second anticipation stride of the trailing leg, decreased activities of the soleus, gastrocnemius medialis and lateralis, and vastus medialis were observed.

Spatiotemporal stride characteristics

In anticipation strides before stair ascent, the only changes were in temporal parameters. The percentage of swing and stance phases for the first anticipation stride of the trailing leg and the second anticipation of the leading leg were significantly different from baseline conditions. In these strides, stance and swing phases occupied smaller and larger percentages of the gait cycle, respectively.

During subjects' anticipation strides preceding stair descent, all changes were spatial. Step length decreased in the first anticipation stride of the leading leg (i.e., the earliest anticipation stride analyzed) as did stride length in the second anticipation stride of the trailing limb (i.e., the latest anticipation stride analyzed).

Discussion

To provide needed insights into the biomechanics of human locomotion, the purpose of this study was to identify the anticipatory stride mechanics of able-bodied individuals as they approached transitions from level-ground walking to stair ascent and descent. Unlike prior studies in this area of research, two consecutive "anticipation" strides of each leg (i.e., leading and trailing legs) preceding the transition strides to the stairs (Fig. 2) were comprehensively assessed.

Hypotheses

The first hypothesis that changes in mechanics would be found in two anticipation strides of both stair ascent and descent was supported. We found significant changes relative to baseline walking for both ascent and descent transitions across all types of data (Figs. 3-7 and Table 1). We also hypothesized that transitions to stair ascent would result in changes consistent with increasing the overall energetics of the body, while transitioning to stair descent would result in changes consistent with decreasing energetics. This hypothesis was supported for stair descent since decreases in velocity and/or translation were observed across all of the anticipation strides (Fig. 3). Interestingly, the largest reductions in these metrics were observed in the earliest anticipation stride (i.e., the first anticipation stride of the leading leg) and then in the latest anticipation stride (i.e., the second anticipation stride of the trailing leg). The middle anticipation strides of stair descent had the most modest decreases in these metrics (Fig. 3). Our hypothesis was not supported regarding stair ascent. Increasing energetics were not observed when examining the center-of-mass mechanics (Fig. 3). Rather, these data suggest that energetics are primarily maintained throughout the anticipation strides of stair ascent, until the latest portion of the latest anticipation stride of stair ascent (i.e., the swing phase of the second anticipation stride of the trailing leg) in which a reduction in velocity was observed. Thus, for both transitions, these data show that the preferred initial conditions preceding stair transition strides is to be walking slower than baseline. These conditions may be due to an increased perception of risk associated with both of these tasks. But, the slower walking speed was slowest and more widespread throughout all of the anticipation stride sequence for descent, which suggests these subjects perceived a greater risk. These assertions are supported by previous investigations of gaze fixation as individuals transitioned from level walking to stairs (e.g., Zietz and Hollands 2009, Miyasike-daSilva et al. 2011), which have shown that subjects fixate on stairs approximately three steps ahead of the stairs (Zietz and Hollands 2009). Those studies also showed subjects look between two and four steps ahead of their current location as they approach stair ascent, and consistently looked four steps ahead prior to stair descent (Miyasike-daSilva, Allard et al. 2011). Including the two anticipation strides and the transition strides (i.e., up to three strides in advance of stairs, Fig. 2), our results indicate that able-bodied individuals modify their biomechanics at least as early as three strides (i.e., approximately six steps) prior to reaching stair ascent and descent, which is a greater distance than these fixation distances reported for stair ambulation, as well as greater than the preparation distance of two steps (i.e., approximately one stride) for stepping on specific targets (Patla and Vickers 2003). These results suggest that biomechanics are altered prior to fixation in the anticipation of stair transitions during walking.

Temporal versus spatial stride modifications for stair ascent versus stair descent

Changes in spatiotemporal stride characteristics were quite different between the transitions to stair ascent and descent (Table 1). First, for ascent, deviations were observed during the middle anticipation strides; while for descent, deviations were found in the earliest and the latest anticipation strides analyzed. Secondly, the changes observed for ascent were temporal, whereas the changes observed for descent were spatial. In the

anticipation of ascent, relatively shorter stance and longer swing phases were observed (Table 1). Changes in percentages of stance and swing are commonly observed when overground walking speed increases (e.g., den Otter et al. 2004, Silverman et al. 2008, Fey et al. 2010), as a result of stance time decreasing and swing time increasing. Interestingly in this study, no increases in walking speed were observed for stair ascent (Fig. 3), and changes in stance/swing percentages appear to be a result of a longer lengthening of the swing phase as opposed to a shortening of stance. These changes are subtle, but could be related to lengthening the duration of these strides to promote more time for neuromuscular task planning. The spatial changes observed for descent were reductions of stride length of the earliest anticipation stride and the latest anticipation stride (Table 1). These reductions correspond with the decreased walking speed observed for stair descent. A possible explanation of these spatial changes is an increased importance of foot placement during anticipation of stair descent.

A lateral preference for altering leading-leg ankle and hip kinematics during anticipation of stair ascent

There were also changes in joint kinematics during the anticipation strides relative to baseline walking (Figs. 4 and 5). These changes in joint kinematics did not occur consistently in the same anticipation strides in which changes in center-of-mass kinematics were noted. In addition, despite widespread reductions in walking speed in the anticipation of stair descent (Fig. 3), very few overall changes in joint kinematics occurred. Those changes that did occur showed a preference for altering the kinematics of the leading leg (Fig. 4) as opposed to the trailing leg (Fig. 5), as well as a preference for modifying ankle and hip kinematics as opposed to kinematics of the knee. For ascent, leading-leg hip extension velocity in terminal swing increased, ankle dorsiflexion velocity in terminal swing decreased, which would result in the subjects placing their foot down faster to engage the ground at heel-strike, possibly to maintain or initiate a pre-planned motor sequence for the following transition strides. Similar changes were also found at the hip for descent in both the leading and trailing leg, in which increased hip extension velocity in terminal swing was observed (Figs. 4 and 5). Although these changes were moderate in their overall magnitude, these difference show a between-limb (i.e., leading versus trailing) difference in how lower-limb motor control is executed in anticipation of stair ascent and descent. Furthermore, a possible explanation of the observed preference for modifying leading leg joint kinematics for stair ascent may be related to the fact that the leading leg is the first to touch a stair of an altered height from the level walking surface (see Fig. 2).

Changes in electromyography consistent and inconsistent with reductions in walking speed

The earlier and more widespread reductions in walking speed during the anticipation of stair descent are consistent with widespread decreases in muscle activity in muscles of both the leading (Fig. 6) and trailing (Fig. 7) legs. Muscles spanning the hip, knee and ankle showed reductions in activity. But, the muscle groups showing the most consistent reductions (i.e., occurring both in terminal stance or swing as well as over the entire stance or swing phases) were the plantar flexors. Reductions of gastrocnemius and soleus activities in

both the leading and trailing legs are consistent with a major role of these muscle groups to regulate anterior/posterior acceleration of the body during walking (Neptune et al. 2001, Allen and Neptune 2012), systematic modifications of activity with walking speed (Yang and Winter 1985, den Otter, Geurts et al. 2004, Fey, Silverman et al. 2010), and altered contributions to anterior/posterior acceleration with changes in walking speed (Neptune et al. 2008). In contrast, during the anticipation strides preceding stair ascent, decreases in activity of some muscle groups (Figs. 6 and 7) were observed despite walking speed not being decreased in corresponding strides of interest (Fig. 3). These fewer changes for ascent were detected when averaging muscle activity over the entire stance phase rather than during a smaller window of data preceding toe-off. For ascent, the only change in muscle activity that occurred during a stride in which walking speed was significantly reduced was a reduced biceps femoris activity in terminal swing of the second anticipation stride of the trailing leg (Figs. 3 and 7).

Limitations and future considerations

Limb dominance (i.e., laterality) was noted prior to study as it was viewed as a potential confounding factor. All nine subjects were right leg dominant, and five of the subjects chose to lead with their right leg, while four of the subjects led with their left leg. In addition to concatenating these nine subjects' data together, we examined these subgroups separately, and found that our data did not show any descriptive differences when grouping by laterality. Future studies with a larger group of subjects are needed to examine with sufficient statistical power if laterality and the choice of leading with or without the dominant limb influences the anticipation of stair transitions. Although, there are a number of prior studies examining lower-limb laterality and the performance of gait which have found no relationship between gait symmetry and laterality (for review, see Sadeghi et al. 2000).

Significance

This study provides new insights into how able-bodied individuals anticipate stair transitions. We showed that anticipatory mechanics differ between stair ascent and descent as well as between leading versus trailing legs. These insights may be important in future applications such as controlling lower-limb assistive devices and the evaluation of fall-prone individuals. One question regarding control of stair transitions is how early can changes in biomechanics be detected. We showed that there are significant biomechanical changes that occur at least as early as the first anticipation stride of the leading leg (i.e., three strides in advance of stairs). However, characteristic biomechanical signatures were not observed, and the changes were not notably different from expected changes as a result of someone reducing their walking speed. For these reasons, a "simple" approach for stair recognition is not yet evident. Prior approaches have used pattern recognition approaches, which interpret combinations of mechanical and electromyographic signals to switch ambulation modes at toe-off or heel-strike of the transition strides (i.e., not the anticipation strides) (e.g., Hargrove et al. 2013, Young et al.

2014). Based on the current study in which diverse sets of changes were observed, similar approaches appear to be needed, especially if only joint kinematics and EMG are interpreted. Since relatively few changes in joint kinematics were found relative to lower-limb EMG, this study also suggests that EMG would be increasingly important to predict stair transitions during the anticipation strides. Finally, similar paradigms that examine how fall-prone individuals and those with gait impairments modify their biomechanics in anticipation of stair ambulation could be useful.

Acknowledgments

This work was supported by U.S. Army grant 81XWH-09-2-0020 and U.S. Department of Education grant H133F130034.

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Figures

Figure 1: Representative instrumented subject (left) and diagram of the lab setup during baseline walking, stair ascent and stair descent conditions (right).

Figure 2: Diagram depicting anticipation and transition strides for level walking to stair ascent (top) and stair descent (bottom) transitions.

Figure 3: Group average anterior center-of-mass translation (left) and velocity (right) during baseline walking strides and anticipation strides of ascent (top) and descent (bottom) transitions. One standard deviation of the baseline walking data are shaded. Vertical dashes indicate toe-off of each stride. Vertical dashes are also equal in length to one standard deviation of each stride data at toe-off. Each trace is plotted versus average duration of the respective stride. Significant within-leg differences relative to baseline walking during terminal stance, terminal swing and over stance and swing for the first (▲) and second (■) anticipation strides of the leading leg as well as the first (▼) and second (●) anticipation strides of the trailing leg are indicated.

Figure 4: Leading-leg group average ankle, knee and hip kinematics during baseline walking strides and anticipation strides of ascent and descent transitions. One standard deviation of the baseline walking data are shaded. Vertical dashes indicate toe-off of each stride. Vertical dashes are also equal in length to one standard deviation of each stride data at toe-off. Each trace is plotted versus average duration of the respective stride. Significant within-leg differences relative to baseline walking during terminal stance, terminal swing and over stance and swing for the first (▲) and second (■) anticipation strides of the leading leg are indicated.

Figure 5: Trailing-leg group average ankle, knee and hip kinematics during baseline walking strides and anticipation strides of ascent and descent transitions. One standard deviation of the baseline walking data are shaded. Vertical dashes indicate toe-off of each stride. Vertical dashes are also equal in length to one standard deviation of each stride data at toe-off. Each trace is plotted versus average duration of the respective stride. Significant within-leg differences relative to baseline walking during terminal stance, terminal swing and over stance and swing for the first (▼) and second (●) anticipation strides of the trailing leg are indicated.

Figure 6: Leading-leg group average electromyography during baseline walking strides and anticipation strides of the ascent (left) and descent (right) transitions. One standard deviation of the baseline walking data are shaded. Vertical dashes indicate toe-off of each stride. Vertical dashes are also equal in length to one standard deviation of each stride data at toe-off. Each trace is plotted versus average duration of the respective stride. Significant within-leg differences relative to baseline walking during terminal stance, terminal swing and over stance and swing for the first (▲) and second (■) anticipation strides of the leading leg are indicated.

Figure 7: Trailing-leg group average electromyography (EMG) during baseline walking strides and anticipation strides of the ascent (left) and descent (right) transitions. One standard deviation of the baseline walking data are shaded. Vertical dashes indicate toe-off of each stride. Vertical dashes are also equal in length to one standard deviation of each stride data at toe-off. Each trace is plotted versus average duration of the respective stride. Significant within-leg differences relative to baseline walking during terminal stance, terminal swing and over stance and swing for the first (▼) and second (●) anticipation strides of the trailing leg are indicated.

Table 1: Group average (standard deviation) spatiotemporal stride parameters during baseline walking strides and anticipation strides of the ascent and descent transitions. Significant ($p < 0.0167$) within-leg differences relative to baseline walking of the first and second anticipation strides of the leading leg, as well as the first and second anticipation strides of the trailing leg are shaded.

Condition	Stride (Leg)	Stride Length (m)	Step Length (m)	Step Width (m)	Stride Time (sec)	Stance Time (sec)	Swing Time (sec)	Stance %	Swing %
Baseline Walking	(Leading)	1.456 (0.081)	0.781 (0.106)	0.089 (0.053)	1.036 (0.019)	0.669 (0.079)	0.367 (0.055)	64.532 (0.027)	35.468 (0.915)
Baseline Walking	(Trailing)	1.453 (0.079)	0.775 (0.105)	0.092 (0.058)	1.037 (0.019)	0.668 (0.078)	0.369 (0.052)	64.423 (0.028)	35.577 (0.831)
Ascent	1st Anticipation (Leading)	1.399 (0.074)	0.734 (0.04)	0.089 (0.004)	1.011 (0.053)	0.635 (0.046)	0.376 (0.016)	62.787 (1.7)	37.213 (1.7)
Ascent	1st Anticipation (Trailing)	1.417 (0.098)	0.758 (0.043)	0.089 (0.019)	1.03 (0.054)	0.647 (0.039)	0.383 (0.02)	62.792 (1.187)	37.208 (1.187)
Ascent	2nd Anticipation (Leading)	1.43 (0.137)	0.753 (0.067)	0.083 (0.018)	1.059 (0.076)	0.665 (0.048)	0.394 (0.034)	62.819 (1.365)	37.181 (1.365)
Ascent	2nd Anticipation (Trailing)	1.368 (0.188)	0.753 (0.072)	0.089 (0.017)	1.061 (0.083)	0.673 (0.049)	0.388 (0.038)	63.438 (1.506)	36.562 (1.506)
Descent	1st Anticipation (Leading)	1.336 (0.097)	0.697 (0.052)	0.1 (0.033)	1.081 (0.081)	0.709 (0.059)	0.373 (0.024)	65.502 (0.897)	34.498 (0.897)
Descent	1st Anticipation (Trailing)	1.399 (0.139)	0.741 (0.07)	0.083 (0.022)	1.079 (0.08)	0.703 (0.052)	0.375 (0.032)	65.207 (1.136)	34.793 (1.136)
Descent	2nd Anticipation (Leading)	1.37 (0.171)	0.745 (0.084)	0.087 (0.028)	1.078 (0.084)	0.696 (0.053)	0.383 (0.036)	64.522 (1.395)	35.478 (1.395)
Descent	2nd Anticipation (Trailing)	1.237 (0.177)	0.716 (0.107)	0.102 (0.022)	1.076 (0.094)	0.706 (0.06)	0.371 (0.038)	65.581 (1.297)	34.419 (1.297)