INFLUENCING HUMAN GAIT DYNAMICS WITH AN ADAPTIVE SPLIT-BELT TREADMILL

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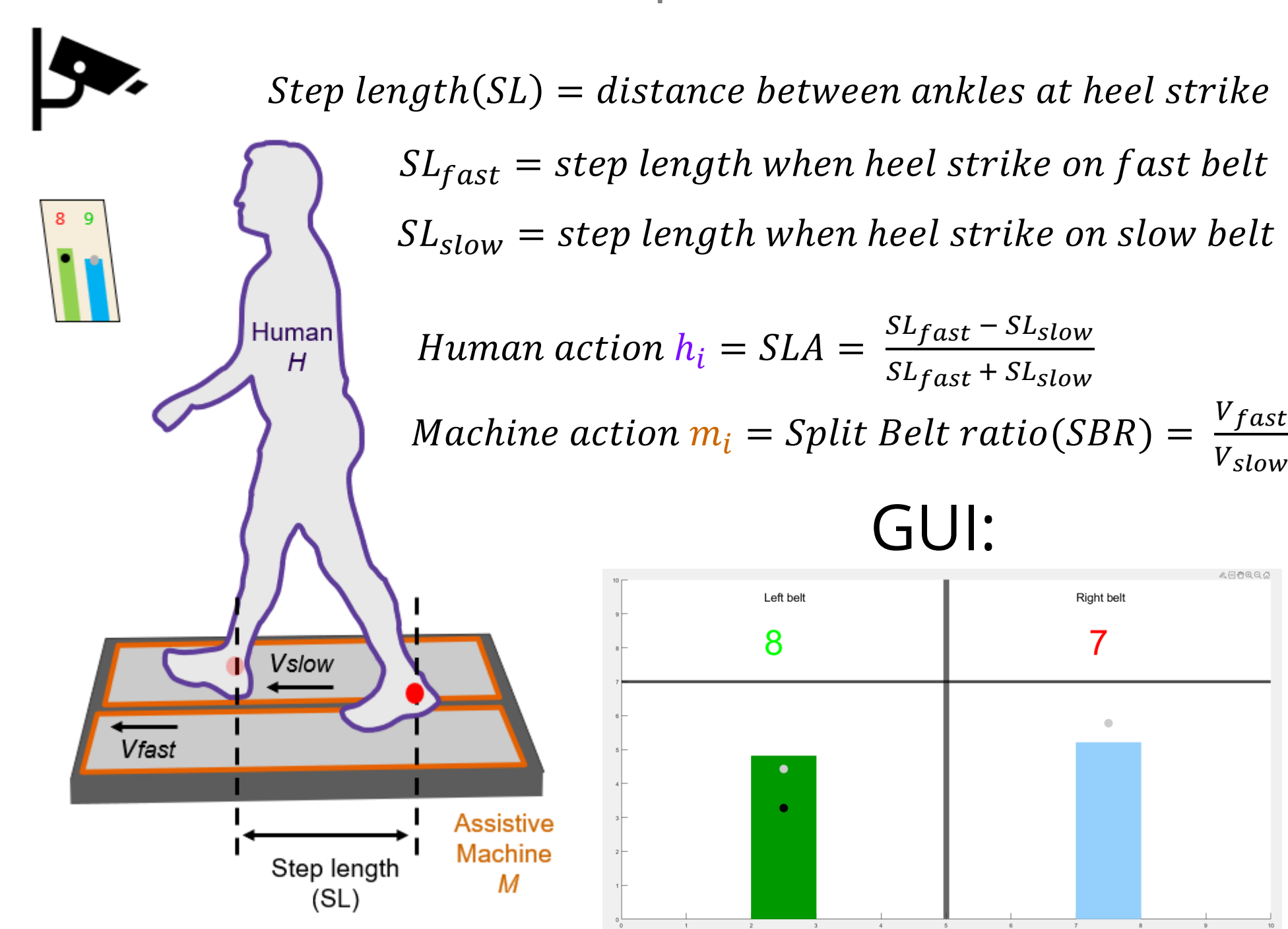Department of Electrical and Computer Engineering, University of Washington, Seattle, WA

Introduction

- Walking on a split-belt treadmill can reduce the energy cost of walking [1,2].

- The treadmill can produce net positive work to a human if they adopt a positive *step length asymmetry* (SLA) .

- Naïve users require guidance and/or long exposure times (> 30 minutes) to learn the strategy, while experienced users might spontaneously adopt it.

- It is unclear how this strategy translates to different walking scenarios on a split-belt treadmill with different *split-belt ratios* (SBR)

Objective: Understand how humans adapt to walking on a split-belt treadmill with varying split-belt ratio

Methods

Experiment 1: Training naïve participants' SLA with visual feedback and observing self-selected SLA with a different split-belt ratio (n = 15)

$Step\ length(SL) = distance\ between\ ankles\ at\ heel\ strike$

$SL_{fast} = step\ length\ when\ heel\ strike\ on\ fast\ belt$

$SL_{slow} = step\ length\ when\ heel\ strike\ on\ slow\ belt$

$Human\ action\ h_i = SLA = \dfrac{SL_{fast} - SL_{slow}}{SL_{fast} + SL_{slow}}$

$Machine\ action\ m_i = Split\ Belt\ ratio(SBR) = \dfrac{V_{fast}}{V_{slow}}$
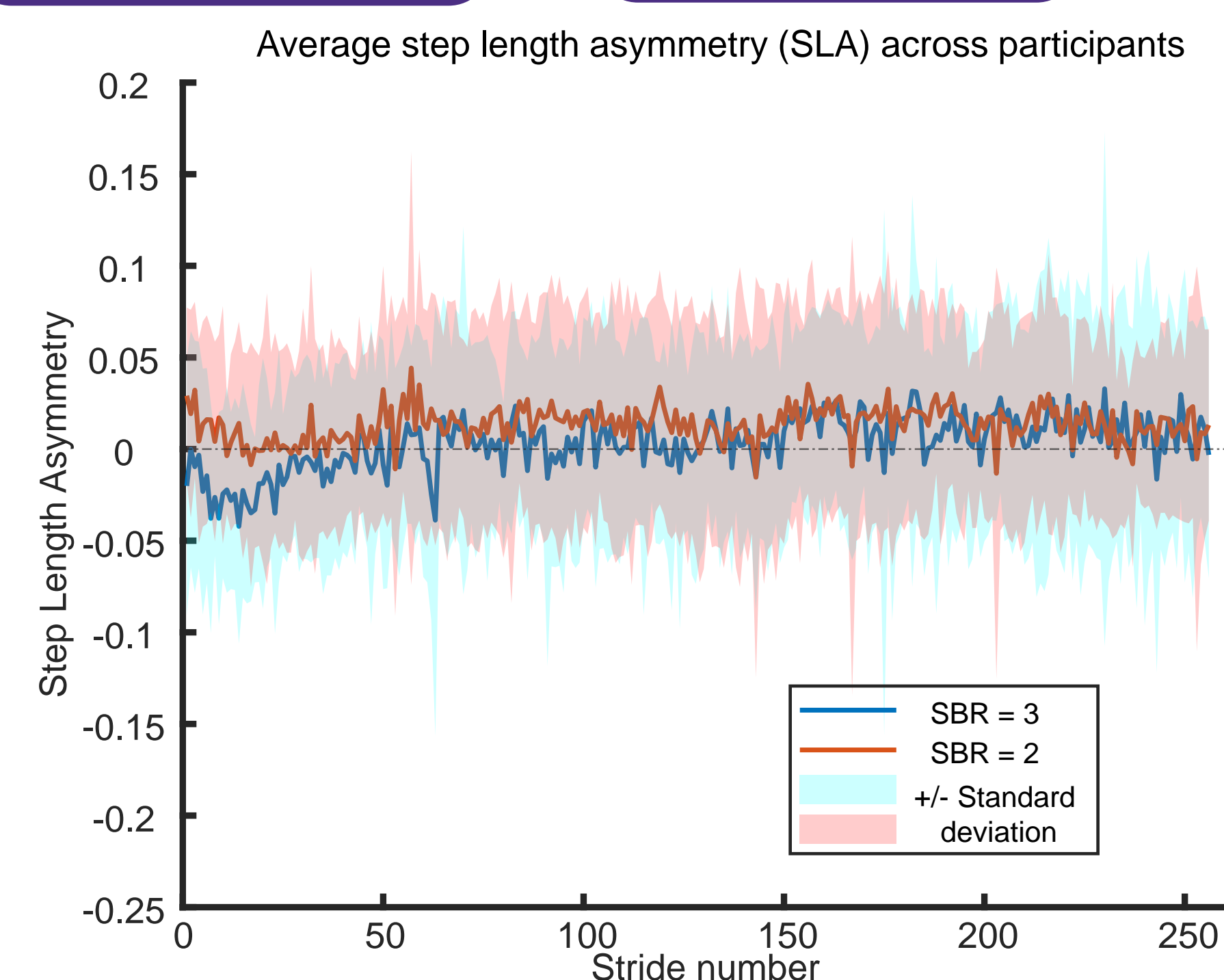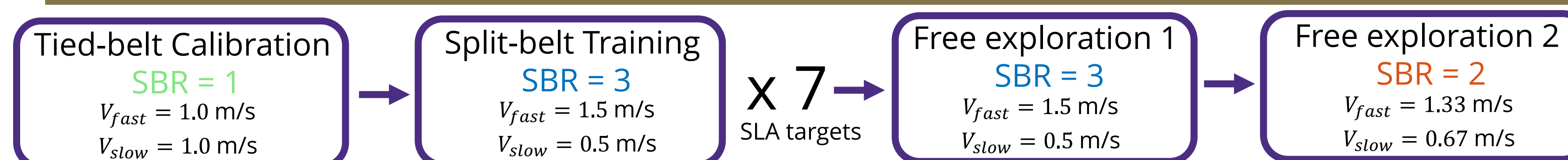
GUI:

Experiment 2: Observing how experienced participants self-select SLA with an adaptive algorithm that dynamically adjusts SBR as a function of SLA (n = 3)
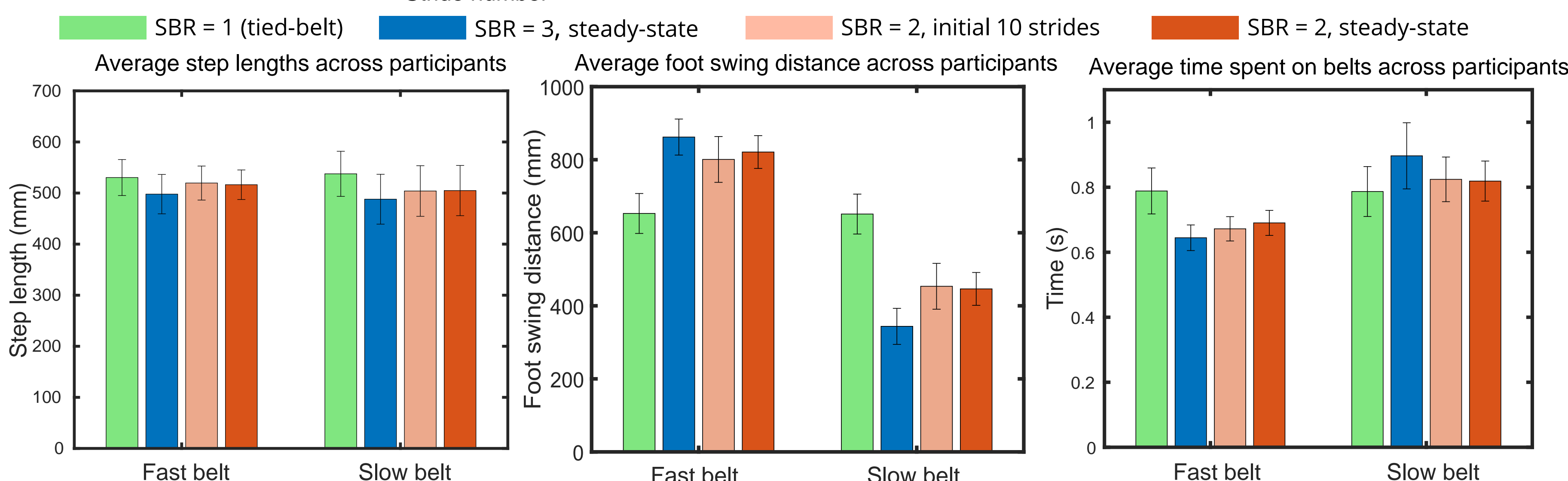
$m_{i+1} = m_{i-1} - a * (m_i - h_i - 2)$

Learning rate a is a parameter we adjust

Experiment 1 - Varying Split-belt ratio after training

Tied-belt Calibration	Split-belt Training		Free exploration 1	Free exploration 2
SBR = 1	SBR = 3	x 7	SBR = 3	SBR = 2
$V_{fast} = 1.0$ m/s	$V_{fast} = 1.5$ m/s	SLA targets	$V_{fast} = 1.5$ m/s	$V_{fast} = 1.33$ m/s
$V_{slow} = 1.0$ m/s	$V_{slow} = 0.5$ m/s		$V_{slow} = 0.5$ m/s	$V_{slow} = 0.67$ m/s

Average step length asymmetry (SLA) across participants

- We followed a similar protocol as [1] and added an additional free exploration trial with different SBR

- In contrast to our hypothesis, we did not observe humans self-selecting positive SLA during free exploration with either SBR.

- No significant difference between steady-state self-selected SLAs of both SBRs

Average step lengths across participants / Average foot swing distance across participants / Average time spent on belts across participants

Legend: SBR = 1 (tied-belt) · SBR = 3, steady-state · SBR = 2, initial 10 strides · SBR = 2, steady-state

Comparing free exploration trials at SBR = 2 to SBR = 3, participants:

- Maintained similar step lengths on both fast belt and slow belt
- Maintained similar leg swing distance on the fast belt while increased leg swing distance on slow belt
- Maintained similar time spent on fast belt while decreased time spent on slow belt

Conclusions and next steps

- Contrary to our hypothesis, the naïve users did not consistently self-select positive SLA after guided exploration with either split-belt ratio.

- The naïve users maintained similar step lengths between two split-belt ratios by changing mainly their slow leg gait pattern when moving from higher SBR to lower SBR.

- Adaptive algorithm showed potential of steering human SLA choices with experienced users.

Experiment 2 - Adaptive Algorithm
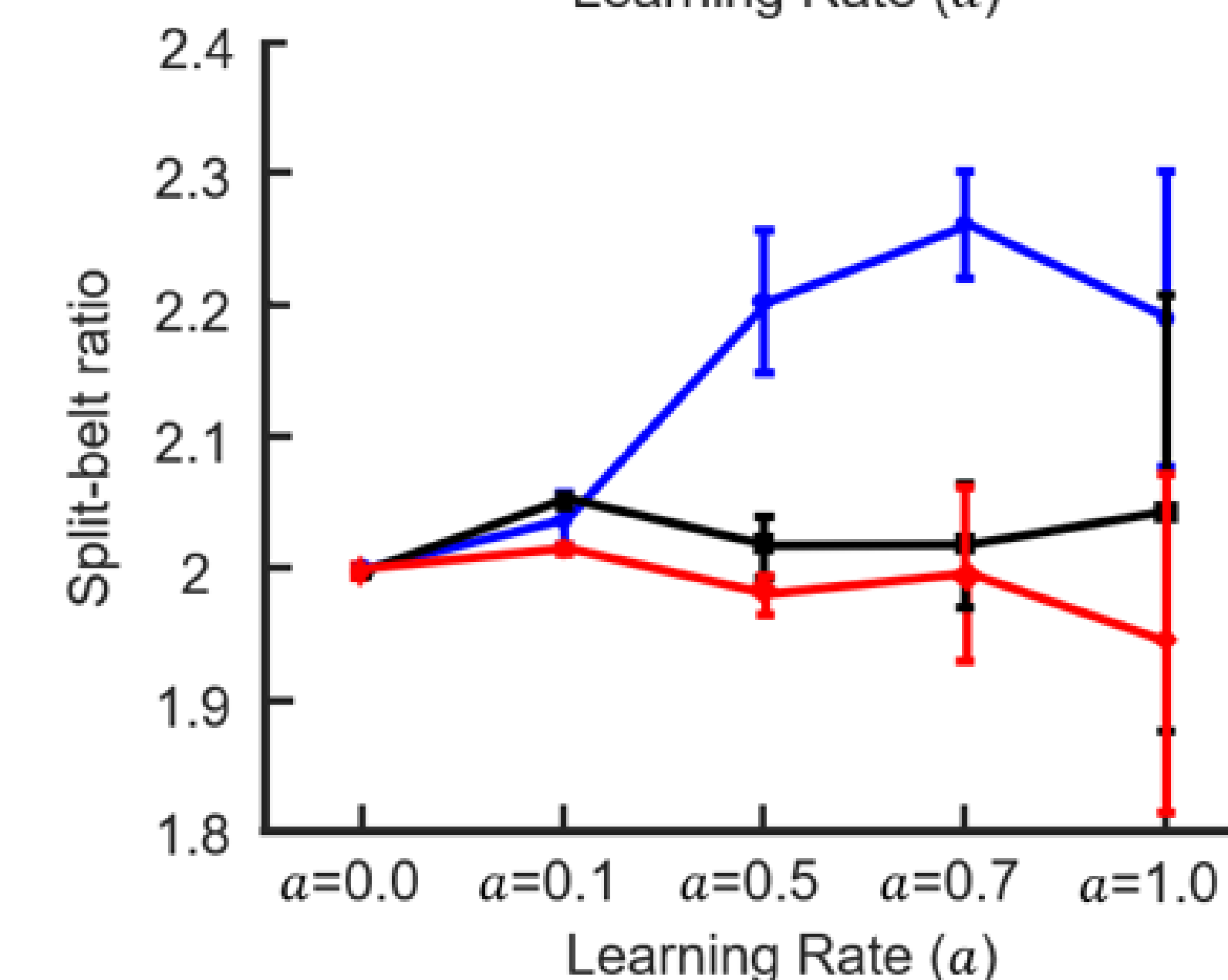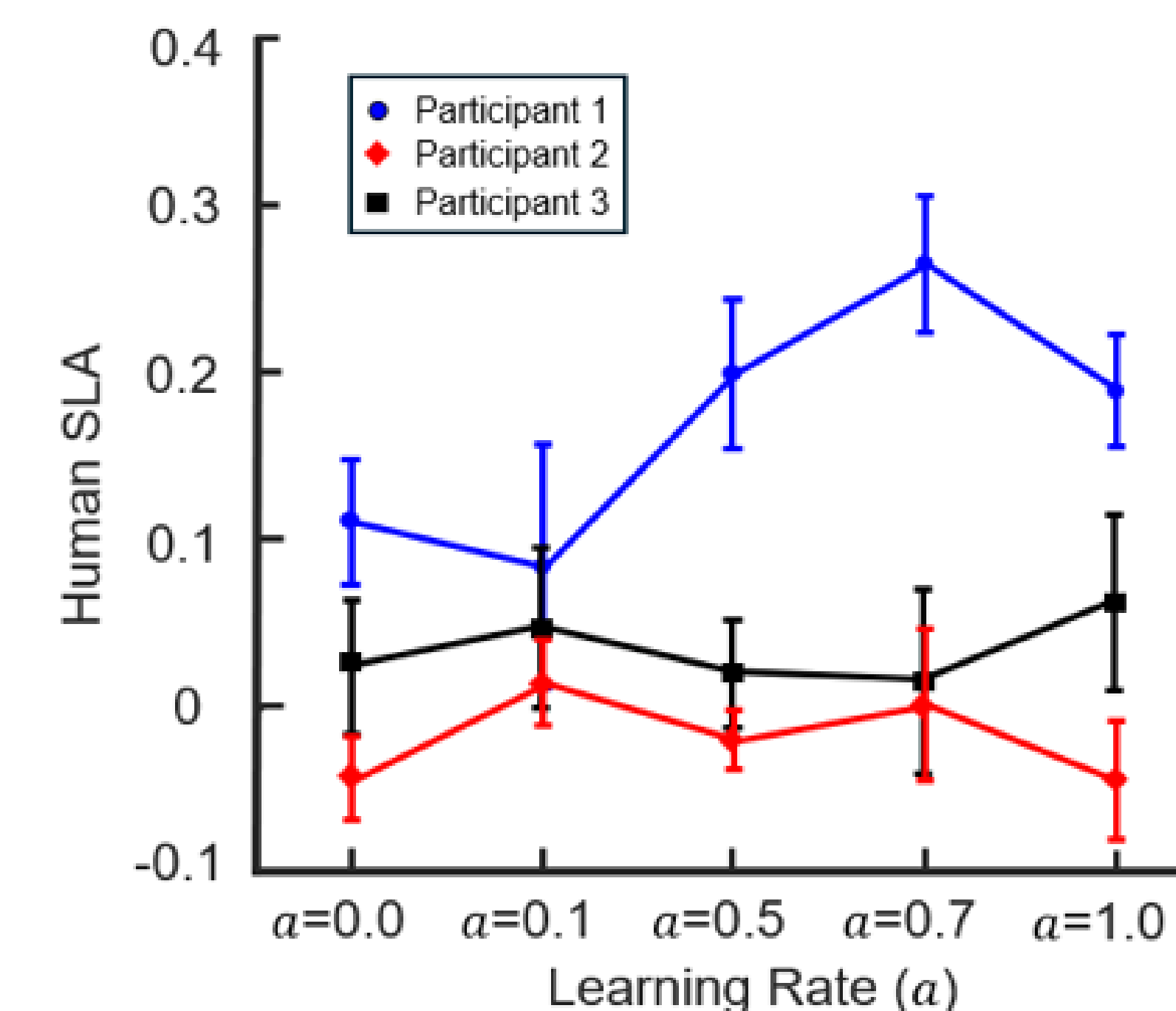
- Experienced users responded differently to time-varying split-belt ratios at different learning rates, a.

- All experienced participants (n = 3) were able to adopt a positive SLA at some learning rates.

References

[1] Sánchez N, Simha SN, Donelan JM, Finley JM. Taking advantage of external mechanical work to reduce metabolic cost: the mechanics and energetics of split-belt treadmill walking. J Physiol. 2019 Aug;597(15):4053-4068. doi: 10.1113/JP277725.

[2] Sánchez N, Simha SN, Donelan JM, Finley JM. Using asymmetry to your advantage: learning to acquire and accept external assistance during prolonged split-belt walking. J Neurophysiol. 2021 Feb 1;125(2):344-357. doi: 10.1152/jn.00416.2020.