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Title: Sit-to-Walk and Sit-to-Stand-and-Walk Task Dynamics are Maintained during Rising at an Elevated Seat-Height Independent of Lead-Limb in Healthy Individuals

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Highlights

- Sit-to-walk (STW) and sit-to-stand-and-walk (STSW) are rise to walk transitions
- Healthy subjects require less vertical force to rise from a higher seat height
- Neither seat-height or lead-limb affect STW or STSW dynamics in healthy subjects
- Normative data independent of lead-limb may inform rise to walk rehabilitation
- Gait initiation (GI) in STSW is distinctive from GI following quiet-standing

Sit-to-Walk and Sit-to-Stand-and-Walk Task Dynamics are Maintained during Rising at an Elevated Seat-Height Independent of Lead-Limb in Healthy Individuals.

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Sit-to-Walk and Sit-to-Stand-and-Walk Task Dynamics are Maintained during Rising at an Elevated Seat-Height Independent of Lead-Limb in Healthy Individuals.

1.0 Introduction

Rising from sitting and the transition to goal-orientated walking are important for independent living. Such transitions include sit-to-stand (STS) and sit-to-walk (STW) where STS is merged with gait-initiation (GI). STS-GI separation, or hesitation [1], can occur in STW and is synonymous with a critical reduction in forward momentum during rising. Separation has been observed during STW in individuals with motor impairment [2,3]. STW is however rarely utilised as a rehabilitation task presumably due to its higher complexity [4]. Instead, in order to manage task complexity and other risks of being upright (e.g. orthostatic intolerance [5]), STS is separated from GI via insertion of a pause after rising in clinical practice, which we term sit-to-stand-and-walk (STSW).

Subjectively, patient groups find rising from high seat heights easier [6], although the effect this has on STW and STSW task dynamics is unclear. Furthermore, whilst patients tend to lead with their affected limb [2], it is unknown whether generation of separate normative dominant and non-dominant lead-limb datasets is necessary in order to facilitate assessment of postural stability recovery.

A stereotypical feature of normal GI from quiet-standing, and during STW, is the controlled separation of centre-of-pressure (COP) and whole-body-centre-of-mass (BCOM) [4]. The horizontal distance between them (COP-BCOM distance) can characterise dynamic postural control: where intact control is indicated if greater distances are tolerated [7].

Thus the aims of this study were to determine whether seat-height and lead-limb affects STW and STSW temporal and kinematic task dynamics including COP-BCOM distance in young healthy individuals.

2.0 Methods

2.1 Participants

Ten healthy undergraduate students gave written informed consent to participate in the study that had received local research ethics committee approval (UREC1413/2014).

2.2 Measurements

Participants attended the gait laboratory once, and following mass and height measurement (Seca, 763 scale-stadiometer), completed 5 trials (at self-selected speed) of 8 conditions: STW and STSW, initiated with either dominant (Dom) or non-dominant (NonDom) limb, at 100% knee-height (KH; floor to knee-joint distance) or 120%KH. Participants sat on an instrumented (300mm diameter pressure-mat, Arun Electronics Ltd, Sussex, UK) height-adjustable stool (Svenerik, Ikea, Sweden) with feet in parallel, shoulder width apart, upon separate force-plates to capture ground reaction forces (GRFs) during rising (Fig. 1).

Participants were cued to rise upon illumination of a light (6m in front) with the task of operating a switch (5m in front of them) to turn it off. In STSW participants paused in standing (mentally count from 1-3) before walking, whereas STW required walking immediately upon rising.

[Fig. 1 here]

A 3D whole-body model was defined by placing 40 reflective markers (Qualysis AB, Sweden) on skin overlying anatomical landmarks [8]. Segments were reconstructed by tracking trajectories using 31 additional markers mounted in accordance with a six degrees-of-freedom marker-set [8]. Kinematic data were acquired using eight infra-red cameras (Oqus-3, Qualisys AB, Sweden) sampled at 60Hz and synchronously recorded with the following analogue inputs at 1020Hz: 4 force-plates (9281E, Kistler Instruments Ltd., UK), the stool pressure-mat, and the light-switch.

2.4 Data Analysis

Raw marker trajectories and analogue data were imported into Visual3D (C-Motion Inc., USA). The light and pressure-mat analogue signals were average-filtered over a 25-frame window.

The marker and GRF data were first smoothed (10Hz and 25Hz 4th order low-pass Butterworth filter respectively [4]) before estimation of BCOM and net COP positions from 4 force-plates. Movement events for STW and STSW (Supplementary Table S1a) permitted the delineation of temporal and kinematic variables (Supplementary Table S2) with respect to the task phases (Supplementary Table S1b) [2,3,9,10].

2.5 Statistics

All data were normally distributed (Kolmogorov-Smirnov 1-sample test, PASW v18.0, IBM Corp., USA). Therefore, the effect of seat-height (100%KH, 120%KH), lead-limb (Dom, NonDom) and their interaction were determined via performance of a two-way repeated measures ANOVA with statistical significance assumed at $p \leq 0.05$.

3.0 Results

Ten (5 female) healthy volunteers (mean±SD 29.1±7.7 years, 171.0±7.7 cm, 73.5±10.9 kg) participated with one being left-limb dominant. Knee-height (461±37 mm) and bi-acromial (shoulder) widths (407±42 mm) were within the normal range [11].

Lead-limb had no significant effect or interaction with seat-height in either task (Table 1). However, in both tasks peak vGRFs (STW: [$F(1,39)=8.568$; $p=0.006$; $\eta^2=0.192$], STSW: [$F(1,39)=6.066$; $p=0.019$; $\eta^2=0.144$]) and vBCOM velocities (STW: [$F(1,39)=27.045$; $p<0.001$; $\eta^2=0.429$], STSW: [$F(1,39)=15.533$; $p<0.001$; $\eta^2=0.301$]) during rising from 120%KH were lower compared to 100%KH irrespective of lead-limb (Fig. 2). No difference in peak hBCOM velocity was observed with either limb.

[Table 1 here]

[Fig. 2 here]

There were no height nor limb effects upon any COP-BCOM distance in either task. Mean pause-times were short and variable (0.84±0.42s). At 120%KH, STW GI time (GI-onset to 1st toeoff; TO1) was shorter (~100ms) [$F(1,39)=8.367$; $p=0.006$; $\eta^2=0.189$] across Dom and NonDom. There were no height or limb effects on any other temporal variables.

4.0 Discussion

Lower vBCOM velocities and vGRFs observed in both STW and STSW at the higher seat are consistent with lower muscle force production and thus effort [12]. However, seat-height had no effect on rise-times or peak hBCOM velocity consistent with previous STS literature [12,13]. This suggests that rise-time and peak hBCOM velocity may be tightly controlled variables in healthy individuals. Whilst STW GI-time (GI-onset to TO1) at 120%KH was shorter, seat-height did not affect movement-onset to GI-onset. This means TO1 at 120%KH occurs earlier than rising from 100%KH presumably due to reduced vertical displacement. This difference (~100ms) is maintained thereafter but its functional significance is questionable as overall STW time was not affected by seat-height.

Lead-limb had no significant effect during either task in healthy individuals. This suggests that pathological STW or STSW function could be determined should differences be observed in patients upon comparison with a normative uni-limb, or averaged across-limb dataset defined within a specific lab environment.

Despite seat-height or lead-limb having no significant effect upon GI dynamic stability in our healthy participants, we observed shorter COP-BCOM distances at GI-onset (TO1; ~13cm across limbs) than previously reported (~23cm [14]) suggesting a reduction in COP-BCOM separation during STSW compared to GI from quiet-standing. Furthermore, STSW lateral and posterior COP displacement at release was not affected by seat-height or lead-limb. However, mean displacement laterally (60mm) was in excess of that previously reported (36mm), whilst posterior displacement (30mm) was lower (47mm) [10]. Adoption of a wide (shoulder-width) stance in our protocol [15] may account for greater lateral COP excursion. In contrast, self-selected pause (in the context of our standardised walking goal) led to modest posterior excursion requirements during GI; it is likely BCOM forward momentum after rising was not completely arrested in our protocol.

The instruction to self-select pause duration after rising in STSW resulted in short, but variable pause-times compared with up to 10s in GI from quiet-standing paradigms [10]. We are currently determining the pause-times self-selected by patients performing STSW. Whilst we acknowledge that our results are based on a modest number of healthy participants, these data reveal that STSW should be considered a distinct task compared to GI from quiet-standing.

In conclusion, 120%KH does not fundamentally affect the transitional temporal and kinematic task dynamics from sitting-to-walking in healthy individuals. Furthermore, the absence of a lead-limb effect suggests that a single normative postural control data-set may provide a valuable tool to assess an individual's rehabilitation within the critical context of transitions from sitting to goal-orientated walking, should differences in our key variables be observed in ongoing studies of patients.

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Figure captions

Fig. 1: Experimental Protocol. This example shows left-leg lead configuration: Participants sat on an instrumented stool at either 100 and 120% knee height (KH), with ankles 10° in dorsiflexion, and feet at shoulder width apart orientated forward. In both STW and STSW conditions on a visual cue, participants rose with their feet on independent portable force-plates and walked forward over two further portable force-plates. Participants performed 5 trials at both seat-heights and lead-limb at self-selected pace. The configuration of force-plates 3 and 4 were changed to allow right lead-limb.

Fig. 2. Mean (±SE) A); Maximum vertical ground reaction force (vGRF) and B); Maximum whole-body-centre-of-mass (BCOM) vertical velocity during rising from 100 and 120% Knee Height (KH) and lead-limb (Dominant [Dom] and Non-Dominant [NonDom]) for STW and STSW. * $p<0.05$ for effect of seat height.

Tables

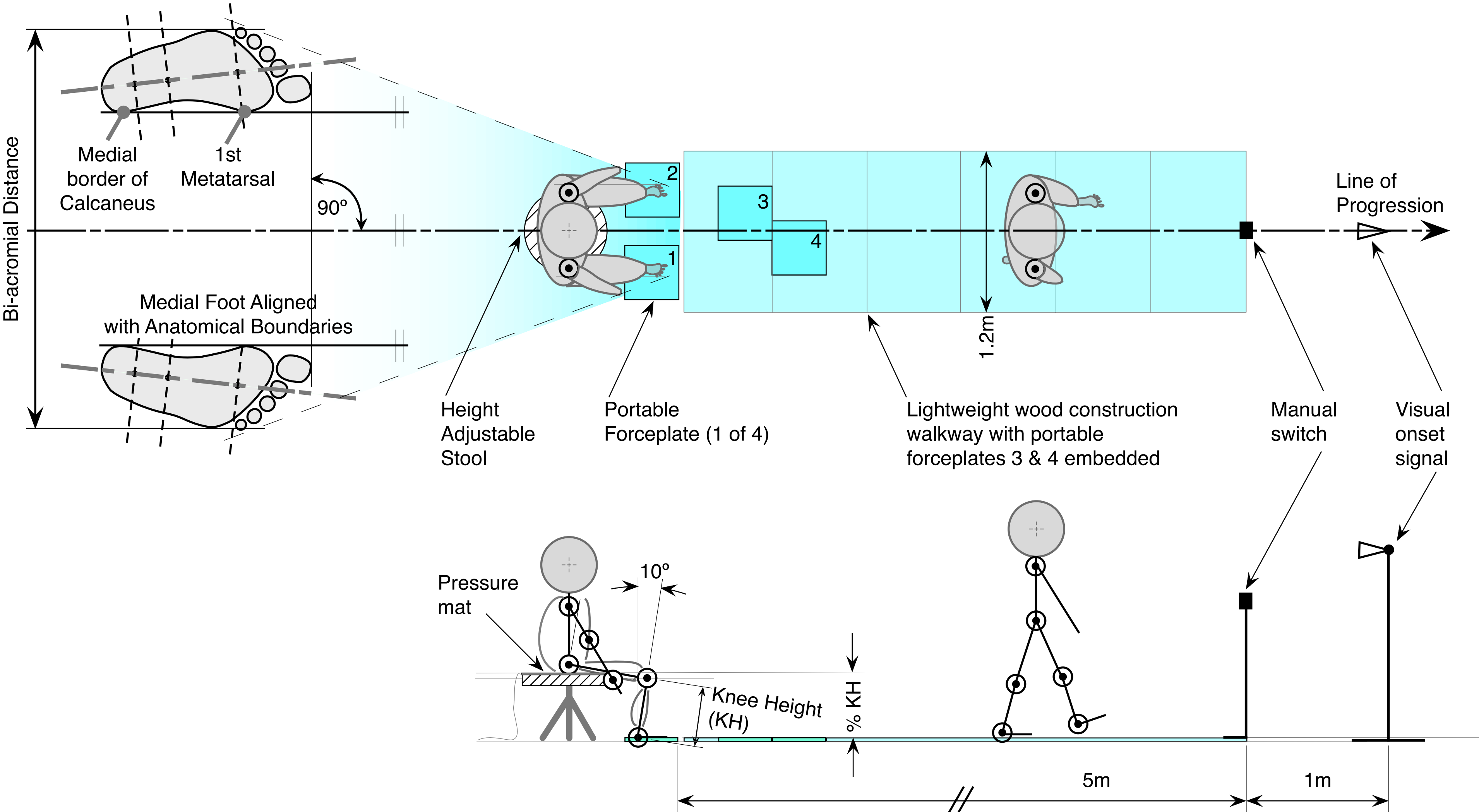
Table 1: Mean (±SE) for temporal, kinetic and kinematic dynamics STW and STSW at 100 and 120% Knee Height (KH) and lead-limb (Dominant and Non-Dominant).

			STW									STSW								
			100				120					100				120				
Phase		Dependent Variable	Dom		Non Dom		Dom		Non Dom			Dom		Non Dom		Dom		Non Dom		
Rise	1	Peak Net Vertical GRF (Normalised to Mass)	1.36	±0.03	1.36	±0.03	1.27	±0.03	1.28	±0.03	**	1.31	±0.03	1.30	±0.03	1.23	±0.03	1.23	±0.03	*
	2	Peak vBCOM Velocity† (m.s^{-1})	0.73	±0.03	0.73	±0.03	0.57	±0.03	0.57	±0.03	***	0.68	±0.04	0.68	±0.04	0.53	±0.04	0.54	±0.04	***
	3	Peak hBCOM Velocity‡ (m.s^{-1})	0.54	±0.02	0.54	±0.02	0.53	±0.02	0.54	±0.02		0.49	±0.02	0.49	±0.02	0.47	±0.02	0.47	±0.02	
	5	COP-BCOM Distance at Seat-off (m)	0.06	±0.01	0.07	±0.01	0.08	±0.01	0.08	±0.01		0.08	±0.01	0.09	±0.01	0.09	±0.01	0.09	±0.01	
	4	COP-BCOM Distance at Upright (m)	0.14	±0.01	0.14	±0.01	0.13	±0.01	0.15	±0.01		0.02	±0.00	0.02	±0.00	0.02	±0.00	0.02	±0.00	
	6	Movt Onset » Seat-Off (Flexion Momentum Time) (s)	0.64	±0.04	0.64	±0.04	0.62	±0.04	0.61	±0.04		0.64	±0.04	0.66	±0.04	0.65	±0.04	0.65	±0.04	
	7	Movt Onset » Upright (Rise Time) (s)	1.25	±0.06	1.25	±0.06	1.16	±0.06	1.17	±0.06		1.39	±0.07	1.46	±0.08	1.33	±0.07	1.35	±0.07	
	8	Movt Onset » GI Onset (s)	0.72	±0.04	0.71	±0.04	0.72	±0.04	0.71	±0.04		–	–	–	–	–	–	–	–	
	9	Seat-Off » BCOM Vertical Vel (Extension Time) (s)	0.26	±0.01	0.26	±0.01	0.25	±0.01	0.24	±0.01		–	–	–	–	–	–	–	–	
	10	Seat-Off » Upright (Extension Time) (s)	–	–	–	–	–	–	–	–		0.75	±0.05	0.80	±0.05	0.68	±0.05	0.70	±0.05	
Pause	11	Upright » GI Onset (Pause Time) (s)	–	–	–	–	–	–	–	–		0.79	±0.14	0.90	±0.14	0.86	±0.14	0.84	±0.14	

GI	12	Peak Swing Limb Vertical GRF (Normalised to Mass)	0.73	±0.02	0.77	±0.02	0.73	±0.02	0.78	±0.02			0.70	±0.02	0.70	±0.02	0.70	±0.02	0.72	±0.02	
	13	COP mediolateral excursion at Release distance (m)	–	–	–	–	–	–	–	–			0.06	±0.01	0.06	±0.01	0.06	±0.01	0.06	±0.01	
	14	COP backward excursion at Release distance (m)	–	–	–	–	–	–	–	–			0.03	±0.01	0.02	±0.01	0.03	±0.01	0.03	±0.01	
	15	Stability: COP-BCOM Distance at GI onset (m)	0.04	±0.01	0.05	±0.01	0.05	±0.01	0.05	±0.01			0.02	±0.00	0.02	±0.00	0.02	±0.00	0.02	±0.00	
	16	Stability: COP-BCOM Distance at TO1 (m)	0.12	±0.01	0.12	±0.01	0.12	±0.01	0.11	±0.01			0.14	±0.01	0.13	±0.01	0.14	±0.01	0.14	±0.01	
	17	GI onset » Release (Release Time) (s)	–	–	–	–	–	–	–	–			0.36	±0.03	0.33	±0.03	0.33	±0.03	0.38	±0.03	
	18	GI onset » TO1 (GI Time) (s)	0.43	±0.03	0.46	±0.03	0.35	±0.03	0.34	±0.03	**		0.61	±0.03	0.61	±0.03	0.60	±0.03	0.63	±0.03	
Step 1	19	Stability: Max COP-BCOM TO1 » IC1 (m)	0.27	±0.01	0.26	±0.01	0.27	±0.01	0.26	±0.01			0.26	±0.01	0.25	±0.01	0.26	±0.01	0.25	±0.01	
	20	TO1 » IC1 (Step 1 Time) (s)	0.41	±0.02	0.40	±0.02	0.41	±0.02	0.41	±0.02			0.43	±0.02	0.44	±0.02	0.43	±0.02	0.43	±0.02	
Step 2	21	Stability: Max COP-BCOM Distance IC1 » IC2 (m)	0.24	±0.01	0.23	±0.01	0.24	±0.01	0.24	±0.01			0.24	±0.01	0.23	±0.01	0.23	±0.01	0.23	±0.01	
	22	IC1 » IC2 (Step 2 Time) (s)	0.59	±0.02	0.58	±0.02	0.58	±0.02	0.58	±0.02			0.61	±0.02	0.62	±0.02	0.61	±0.02	0.62	±0.02	
Step 3	23	Stability: Max COP-BCOM Distance IC2 » IC3 (m)	0.26	±0.01	0.26	±0.01	0.27	±0.01	0.26	±0.01			0.27	±0.01	0.26	±0.01	0.26	±0.01	0.26	±0.01	
	24	IC2 » IC3 (Step 3 Time) (s)	0.56	±0.01	0.56	±0.01	0.56	±0.01	0.55	±0.01			0.57	±0.01	0.58	±0.01	0.57	±0.01	0.57	±0.01	
All	25	Movt Onset » IC3 (Overall Movement Time) (s)	2.71	±0.08	2.70	±0.08	2.61	±0.08	2.59	±0.08			4.39	±0.18	4.55	±0.18	4.40	±0.18	4.45	±0.18	
	26	Light-On » IC3 (Overall Task Time) (s)	3.04	±0.09	3.05	±0.09	2.93	±0.09	2.89	±0.09			4.75	±0.18	4.97	±0.18	4.70	±0.18	4.77	±0.18	

†Vertical BCOM Velocity; ‡Horizontal BCOM Velocity

– Dependent variable not analysed in this task
* Significant within task for seat-height effect $p<0.05$
** Significant within task for seat-height effect $p<0.01$
*** Significant within task for seat-height effect $p<0.001$


Bi-acromial Distance
Medial
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2
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1.2m
Line of
Progression
Height
Adjustable
Stool
Portable
Forceplate (1 of 4)
Lightweight wood construction
walkway with portable
forceplates 3 & 4 embedded
Manual
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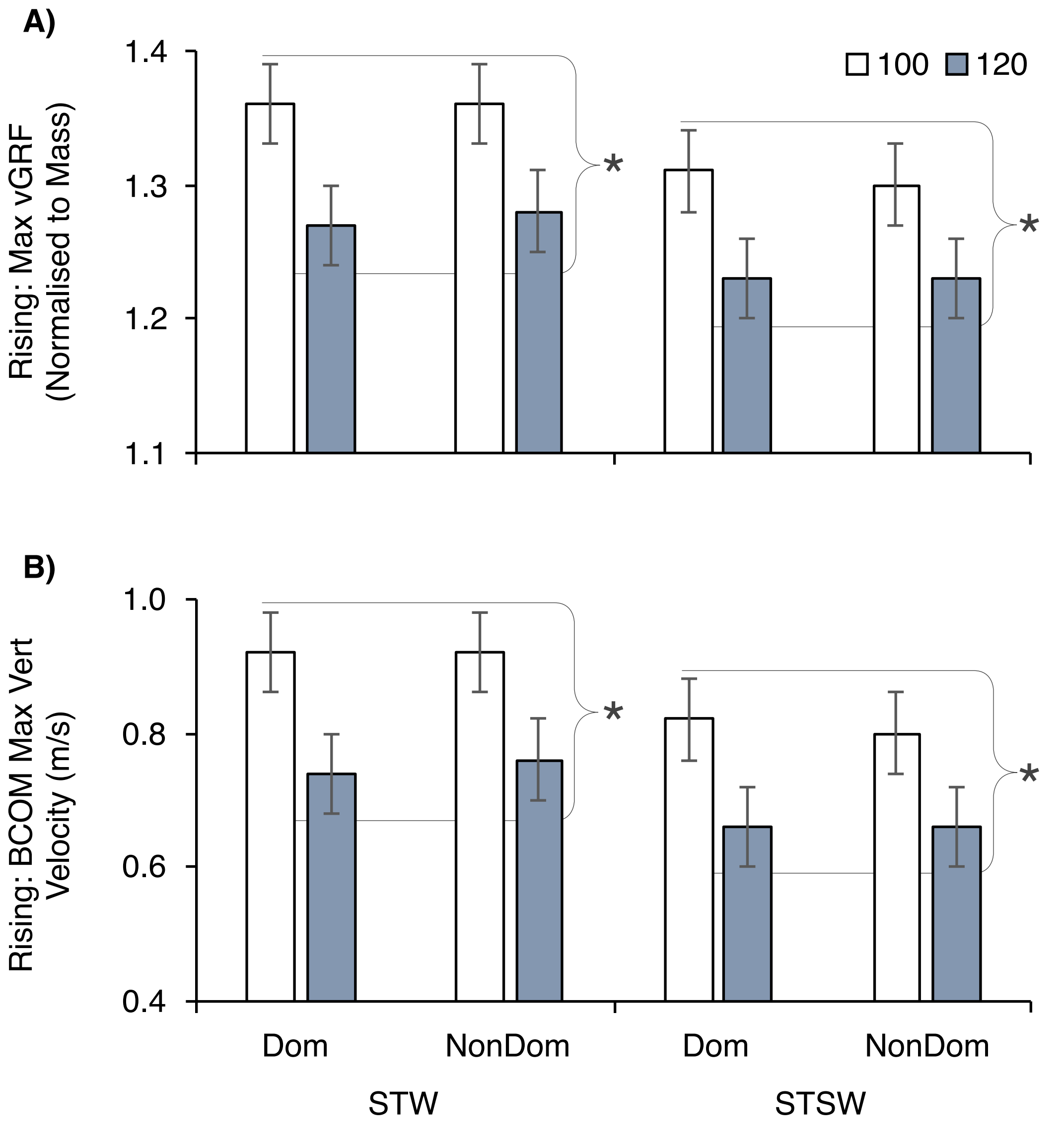
1m


A)
Rising: Max vGRF (Normalised to Mass)
1.4
1.3
1.2
1.1
100
120
*
*
B)
Rising: BCOM Max Vert Velocity (m/s)
1.0
0.8
0.6
0.4
*
*
Dom
NonDom
Dom
NonDom
STW
STSW