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Relative effort changes during sit to stand and stand to sit transition following muscle damage

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Abstract. Sit to stand transition (STST) is sometimes considered as the reverse task of the stand to sit transition (StST). The challenges of STST and StST are exemplified by the welfare issue of elderly humans being unable to rise from a chair and sit on a chair due to loss of muscle strength. STST and StST like any activity of daily living loads the musculoskeletal system (load) and muscles have to produce adequate force (capacity) for fulfilling the task safely. The aim of this study was: a) to investigate the relative effort changes of STST and StST caused by DOMS and b) identifying which task is most demanding before and after muscle damage protocol. Eighteen physically active females participated in this study. Two-way ANOVA (4 times × 2 muscle groups) was used to analyze DOMS, two-way ANOVA (2 times × 2 tasks) was used to analyze the relative effort and two-way ANOVA (5 times × 2 muscle groups) was used to analyze isometric average peak torque. All muscle damage indices altered significantly after the eccentric exercise confirming that muscle damage did occur. In both tasks the relative effort is almost the same although the muscle activation and contraction is different. Those results could be helpful in rehabilitation of individuals with movement difficulties due to aging or other pathology.
Key words*: biomechanics, muscle damage, DOMS, sit to stand.*

Introduction

Sit to stand transition (STST) is sometimes considered as the reverse task of the stand to sit transition (StST). Visually these two tasks may look reversely similar, however, the muscle activity to accomplish them is different. During STST, gravity is opposing the lifting the center of mass and it is achieved mainly by the concentric action of quadriceps. On the other hand, during StST, gravity is forcing the center of mass lower and this fall is mainly regulated by the eccentric action of quadriceps. Both movements are thought to be some of the most mechanically demanding tasks performed in our daily living.

The challenges of STST and StST are exemplified by the welfare issue of elderly humans being unable to rise from a chair and sit on a chair due to loss of muscle strength. The inability to perform any of these task can lead to impaired functioning and mobility in activities of daily living (1, 2).

Many researchers have investigated the mechanics of STST and StST in healthy young and elderly people (3-9) as well as in various pathological cases such as stroke (10-12), Parkinson (13, 14), hemiplegia (15, 16), obesity (17, 18), osteorthritis and after hip-knee arthroplasty (19-21). The mechanics of STST is also affected by chair characteristics such as the height of chair, as well as arm movement and feet positioning (2). From another point of view researchers studied STST with additional back loading and load burdens on lower limbs to understand strategy changes of the musculoskeletal system by stressing the muscles artificially (22, 23). Despite the large number of studies examining the muscle activity during STST, the research on StST is limited (24, 25).

Many researchers suggest that muscle weakness and limited strength is the major contributing factor to change the strategy of a movement or to fail accomplishing and lead to fall (26, 27).

Apart from aging, muscle weakness can also be followed after fatigue or muscle damage in healthy individuals. Muscle damage is very common to those involved in acute concentric or eccentric muscle contraction after long time of rest.

It is important to note that any unaccustomed exercise of high intensity or duration or exercise consisting of lengthening muscular actions (eccentric exercise) induces muscle damage in all ages (28, 29). Muscle damage affects the peak joint torque; range of motion (ROM) and 48 hours after it creates delayed onset muscle soreness (DOMS) accompanied with pain (29).

STST and StST like any activity of daily living loads the musculoskeletal system (load) and muscles have to produce adequate force (capacity) for fulfilling the task safely. Thus, a subject-specific load/capacity ratio is created, also referred by some investigators as ‘’relative effort’’, reflecting the demands in every task (27, 30, 31). Elderly with decreased strength capacity alter their strategy in movements due to ageing and their comorbidities.

Most researchers have investigated the immediate changes of this ratio by increasing the loading with additional weights (22, 23). The capacity in some other studies has been investigated as a function of ageing, disease or artificial muscle weakness (27, 31, 32). Thus, any change in relative effort can only be studied with experimental models in healthy young individuals or with long-term studies in elderly. Any increase of this ratio resulted from a reduction of the capacity will challenge the locomotor system and change the mechanics of movement due to the new higher demands.

Exercise-induced muscle damage is an experimental model that alters this ratio because the capacity is dramatically decreased (29, 32, 33) introducing higher stress to the locomotor system and muscle weakness.

Hence, the aim of this study was: a) to investigate the relative effort changes of STST and StST caused by DOMS and b) identifying which task is most demanding before and after muscle damage protocol.

Material and Method

Eighteen physically active females (25.1±3 years; 165±7cm; 55.2±5kg), without any musculo-skeletal injury or other pathology volunteered to participate in this study after signing an informed consent form approved by the University’s ethics committee. All participants visited the laboratory six times individually within one-week period (Table I).

Isokinetic Exercise Protocol & Relative Effort. A 10 min warm up protocol included cycling at 50W (Monark, Sweden) and stretching of the major muscle groups of the lower limbs.

Eccentric exercise was conducted on an isokinetic dynamometer (Cybex-Norm, Ronkonkoma, NY). Participants were securely seated at 100° hip flexion angle. The knee ROM was set at 0-100°. Gravitational correction at 45° of knee flexion was also performed. The muscle damage protocol consisted of 5x15 eccentric maximal voluntary actions of the knee flexor and extensor muscle groups in sequence at 60°/s (34, 35). Both legs were exercised randomly in two separate bouts with a 5-min recovery between them and a 3-min rest interval between each of the five sets.

The angle of 70° for maximum isometric knee extension was selected as this angle was found to be very close to the angle of maximum torque during STST and StST after pilot measurements of our sample. The maximal knee joint extension moment during the STST and StST was normalized to the maximum isometric knee extension creating a relative effort ratio for knee extensors.

Muscle damage indices & Data collection. Muscle damage indices (32, 34, 35) included average isometric maximum torque at 70° and 30° of knee flexion, measurement of pain through DOMS using a visual analogue scale ranged from 0 (no soreness) to 10 (extremely painful) and creatine kinase (CK).

Knee joint kinematic and kinetic data were collected via, a 10 camera optoelectronic system (Vicon-T40, Oxford, UK), sampling at 100Hz and a BERTEC (4060-15) force plate sampling at 1000 Hz. A functional calibration model with 24 retro-reflective markers attached to the pelvis and lower extremities was employed. The position of the markers was marked with permanent pen (lasting 5-7 days) in order to decrease test-retest variability. In this model, the joint centers and axes of rotation are calculated in two stages: static and dynamic. In the static stage, the standard Davis model is used to define the initial position of joint centers and axes of rotation (36). The subject is then asked to rotate the lower limb joints and the new joint positions as well as axes of rotations are refined based on a mathematical optimization procedure (37). Kinetic data were normalized to body mass.

STST and StST tasks & Definition of Phases. An armless and backless seat fixed at the standard height of 43cm was used for the task. Participants were instructed to perform five StST, triggered with voice at self-selected speed. Hands were crossed on the chest throughout the task and feet were positioned at pelvic width in front of the seat.

StST was separated in three phases adapting a similar methodology for sit to stand from the literature (22, 23, 32). From the quiet standing position, Phase 1 started when the vertical force plate component changed two standard deviations from serenity and ended at maximum dorsi flexion; Phase 2: from the end of phase 1 until hip marker vertical velocity was zeroed (first contact with the seat); and Phase 3: from the end of phase 2 until the ground reaction force signal appeared to be unruffled.

Statistics Analysis. Paired t-tests between left and right sides kinematic measurements showed no significant differences. Thus, the right side was used for analysis. The average of five StST trials per subject was used in data analysis. Paired t-tests were used to investigate differences off all kinematic, kinetic and CK measurements pre and 48 hours post exercise. Two-way ANOVA (4 times × 2 muscle groups) was used to analyze DOMS, two-way ANOVA (2 times × 2 tasks) was used to analyze the relative effort and two-way ANOVA (5 times × 2 muscle groups) was used to analyze isometric average peak torque. Significant interactions and main effects were further investigated using Bonferroni post hoc analysis for multiple group comparisons. The level of significance was set to 0.05.

Results

Muscle damage indices duration StST. All muscle damage indices altered significantly after the eccentric exercise according to the literature confirming that muscle damage did occur (Table II). DOMS increased and isometric average peak torque decreased ($p<0.05$) at all-time points. Only 24 hours after the eccentric exercise, knee extensors strength was significantly lower compared to flexors. Serum CK activity was elevated significantly 72h post exercise.

StST. The total duration of the task increased significantly by 18% ($p<0.05$). Separately, the first and second phase increased by 11% and 85% respectively ($p<0.05$).

Table 1. One-week period experimental procedures for each participant

-72h (Familiarization with Eccentric Exercise)	**-24h**	**0h** (Muscle Damage)	**24h**	**48h**	**72h**
Testing of MKJT	MDC	Testing of MKJT DOMS Blood sampling	Testing of MKJT DOMS	Testing of MKJT MDC DOMS	Testing of MKJT DOMS Blood sampling

MKJT - Max Knee Joint Torque; DOMS elayed onset muscle soreness; MDC-Movement Data Collection

Table II. Muscle damage indices ANOVA results, CK paired t-test results. Data are reported as mean (SD)

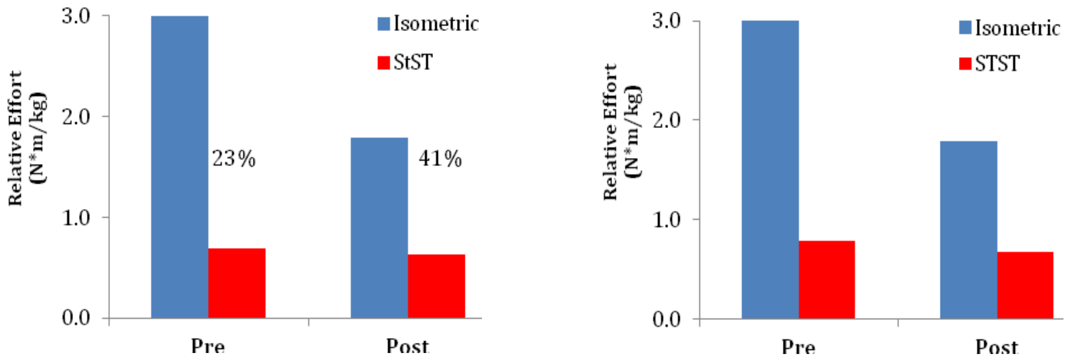
Muscle Damage Indices	**Pre**	**Immediately after**	**24 h**	**48 h**	**72 h**
IAPT ext (Nm)	159.6 (28.1)	121.4 (19.4)*	97.5 (33.5)*	91.7 (31.1)*	106.4 (31.9)*
IAPT flex (Nm)	93 (15.1)	72.2 (12.2)*	66.4 (14.5)*	52.1 (19.1)*	59.7 (20.5)*
IAPT ext (%)	100	76.2 (8.9)*	60.3 (19.5)*	56.9 (17.5)*	66.5 (20.1)*
IAPT flex (%)	100	78.1 (13.1)*	71.4 (11.5)*	56.1 (17.7)*	64 (19.2)*
CK (U/I)	180 (119)	NM	NM	NM	5,359(2,156)*
DOMS (Kneeext)	0	NM	4.9 (1.5)*	8 (2.1)*	5.7 (1.6)*
DOMS(Knee flex)	0	NM	4.5 (1.6)*	7.8 (2)*	6 (2.1)*

*IAPT ext (Nm): isometric average peak torque absolute values of knee extensors; IAPT flex (Nm): isometric average peak torque absolute values of knee flexors; IAPT ext (%): isometric average peak torque of knee extensors expressed as % of pre exercise values; IAPT flex (%): isometric average peak torque of knee flexors expressed as % of pre exercise values; CK (U/I):creatine kinase; DOMS: delayed onset muscle soreness; NM: not measured; *Significantly different compared to pre values (p<0.05)*

Table III. StST&STST Kinematic and kinetic measurements pre and 48 hours after muscle damage protocol. Paired t-test results (p<. 05*), data are reported as mean (SD)

StST Duration		**Pre**		**Post**		**Sig *(P)***
Total (sec)		1.88	(0.25)	2.21	(0.24)	0.008*
Phase 1 (sec)		0.92	(0.07)	1.02	(0.21)	0.05
Phase 2 (sec)		0.22	(0.05)	0.4	(0.11)	0.000**
Phase 3 (sec)		0.74	(0.21)	0.78	(0.2)	0.6
Phase 1 (% of Total time)		50	(7)	46	(6)	0.08
Phase 2 (%of Total time)		11	(3)	18	(5)	0.000*
Phase 3 (%of Total time)		39	(7)	36	(7)	0.12
Kinematics						
Knee (deg)	Min	2.4	(3.58)	1.42	(6.29)	0.15
	Max	86.87	(5.16)	83.59	(5.12)	0.01*
	ROM	84.47	(9.57)	82.17	(7.88)	0.01*
Kinetics						
Knee	Moment (N*m/kg)	0.69	(0.19)	0.63	(0.28)	0.14
	Power (W)	1.3	(0.32)	0.85	(0.41)	0.002*
Max GRF % of Body Weight		62	(7.2)	60	(7.9)	0.48
Slope (N/sec)		155	(53)	130	(50)	0.08

STST Duration		Pre		Post		Sig *(P)*
Total (sec)		2.53	(0.2)	2.91	(0.58)	0.01*
Phase 1 (sec)		0.44	(0.09)	0.46	(0.09)	0.56
Phase 2 (sec)		0.30	(0.07)	0.47	(0.14)	0.001*
Phase 3 (sec)		1.79	(0.2)	1.98	(0.42)	0.15
Phase 1 (% of Total time)		17	(3)	16	(2)	0.08
Phase 2 (%of Total time)		12	(2)	16	(4)	0.001*
Phase 3 (%of Total time)		71	(4)	68	(5)	0.09
Kinematics						
Knee (degr)	Min	-1.32	(4.73)	1.31	(5.47)	0.04*
	Max	86	(6.1)	83.7	(5.4)	0.03*
	ROM	87.32	(6.71)	82.41	(7.73)	0.005*
Kinetics						
Knee	Moment (N*m/kg)	0.77	(0.19)	0.64	(0.21)	0.02*
	Power (W)	1.45	(0.3)	0.97	(0.2)	0.001*
Max GRF % of Body Weight		64	(7)	60	(9.1)	0.03*
Slope (N/sec)		450	(123)	316	(140)	0.003*



(a) **(b)**

Figure 1. The levels of effort needed to execute a STST before and after the muscle damage protocol

Discussion

In the present study, muscle damage indices altered according to the literature. The duration of both StST and STST were increased due to muscle pain and the reduction of muscle strength capacity. This increase was mainly attributed in the second phase (transfer phase) of both tasks, which had the highest increase (Table III). In that phase muscles are highly activated and act almost isometricaly resulting a slower and more difficult transition from and to the chair (38). Moreover the slower movement also resulted significant reduction in knee joint angular velocity in both tasks

Although the knee joint power and the rate of force production (slope) decreased significantly in both tasks, the other kinetic parameters of knee joint in StST and STST altered differently (Table III). In StST the maximum knee joint moment and GRF were unaffected 48 hours after the muscle damage protocol. On the other hand the maximum knee joint moment and GRF were significantly reduced. That possibly happened because in StST the eccentric muscle activation is higher than the concentric action in STST. Moreover in STST individuals in pre exercise condition may chose to lift their body with higher muscle strength production than the actual needed strength.

The relative effort needed to execute a StST and a STST pre and 48hours after the exercise was almost the same with no significant statistical differences. In both tasks individuals used almost the same knee joint torque to sit and standing up pre and after the exercise however the maximum isometric knee joint torque at the same knee joint angle were dramatically decreased. Thus the relative effort increased significantly in StST and

STST after the muscle damage mostly due to the significant reduction of the maximum strength capacity. To the literature the principle of relative effort is used to identify the demands of a task and to predict risk of fall especially in elderly individuals who act closer to their maximal capabilities (30, 31, 39, 40). According to the literature the STST relative effort in young individuals is 30-40% while for elderly adults increased up to 80% (27, 30). Our results are similar to those reported to the literature and show that any reduction of muscle strength affects the relative effort even in simple tasks of daily living.

Our study shows the mechanical demands of StST and STST before and after muscle damage. In both tasks the relative effort is almost the same although the muscle activation and contraction is different. Those results could be helpful in rehabilitation of individuals with movement difficulties due to aging or other pathology. Moreover our findings could be used in design of robotic supporting devices and intervention training programs to prevent risk of falls.

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