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Using wearable inertial sensors to detect different strategies for the sit-to-stand transition in multiple sclerosis

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ABSTRACT

INTRODUCTION: The sit-to-stand (Si-St) transition is an essential activity of daily living (ADL) which is fundamental to maintaining functional independence. It can often be compromised in patients with neurological disorders such as multiple sclerosis (MS). **OBJECTIVE:** The aim of the current study was to determine if different strategies can be detected in the performance of the sit-to-stand transition using gyroscope metrics from wearable inertial sensors in MS and healthy participants. **METHODS:** 12 ambulatory persons with MS (PwMS) with an EDSS of 1-5.5 were compared with 11 healthy volunteers. Participants performed a Si-St transition and a Timed 25 Foot Walk (T25FW) while fitted with wearable inertial sensors (x-io NGIMU) on the thigh and sternum. Each sensor node recorded 9 channels of data (3 each of accelerometers, gyroscopes, and magnetometers) over Wi-Fi onto a computer using software provided by the manufacturer. Analysis of wave forms was done using Matlab and peak detection algorithms based on a 6 Hz low pass filter of the signal. **RESULTS:** The effect of disability on the Si-St transition was that the peak of thigh pitch angular velocity was lower in PwMS than the healthy volunteers (p=0.045, Cliff's $\delta = 0.500$). The average duration of the momentum transfer phase of sit-to-stand was longer in PwMS in comparison to healthy (p=0.039, Cliff's delta=0.515). The duration of momentum transfer was strongly correlated with peak thigh angular velocity but only weakly correlated with T25FW performance or the patient reported measures of disability (MSWS-12 and EDSS-s). **CONCLUSION:** The durations of momentum transfer derived from inertial sensor measurements reflect different movement strategies used by PwMS and healthy individuals for getting out of a chair.

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CCS CONCEPTS

• **Applied computing → Life and medical sciences**.

KEYWORDS

gyroscopy, inertial motion unit, IMU, disability

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1 INTRODUCTION

The most prevalent symptoms of multiple sclerosis (MS) include mobility impairment, peripheral muscle weakness, and fatigue. The sit-to-stand (Si-St) transition is a precursor to movements required in daily life and is essential in maintaining functional independence. A decreased ability to perform Si-St movements can accelerate disability and reduce functionality for people with MS, impacting an individual's QoL and also increasing the risk of falls during ambulation [2, 4].

The Si-St transition is an effective task in assessing the biomechanics of lower limb function [4, 5]. The cognitive choice for PwMS during the Si-St transition is how to prioritise two demands that are both often compromised in MS: strength and balance [2]. Previous studies have attempted to separate the Si-St transition into phases on the basis of differentiating certain kinematic parameters and variability of movements [5]. Fundamental movements in all Si-St transitions include impulse, momentum transfer, extension, and stabilisation [4, 5].

Figure 1 summarises the different stages of the Si-St transition, and the movements that are involved in the progression of each stage to the next. Impulse (I) causes forward flexion of the trunk, which displaces the centre of mass (COM) forward in order to move out of the seated position. The seat-off stage occurs during and after the momentum transfer (MT) phase, accompanied by COM displacement upwards as a result of the upward momentum generated by the lower limbs which is facilitated by dorsiflexion (DF). The final standing posture is achieved by extension (E) of the hip and knee, followed by stabilisation (S).

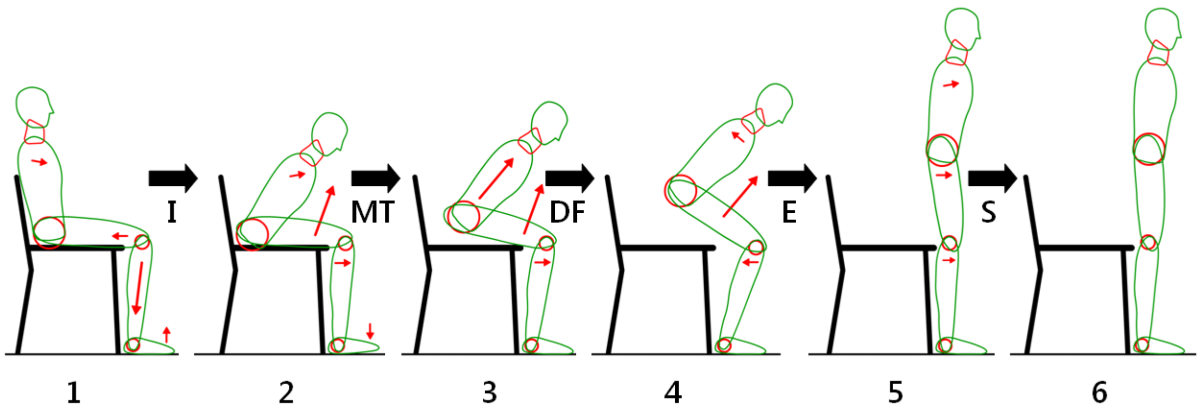

Figure 1: Phases of Sit-to-Stand Transition: Impulse, Momentum Transfer, Dorsiflexion, Extension, Stabilisation

Previous studies have demonstrated that in healthy persons the impulse phase precedes any thigh movements because it facilitates momentum transfer as seat-off occurs [4, 5]. PwMS may use an alternative strategy for the Si-St to compensate for reduced knee extension strength, which involves increased flexion of the torso to move the COM forward as a counterbalance to aid seat off. When the COM moves forward, the moment with the floor moves forward toward the middle of the feet, the point of greatest stability. This strategy reduces the early phase demands on the knee extensors (e.g. quadriceps), while shifting the burden of raising the torso to the stronger hip extensors (e.g. glutei) later in the Si-St transition [1]. The disadvantage of the trunk flexion strategy is that it is much slower and more awkward. This change in strategy results in three changes that should be detectable using inertial sensors [2, 3]:

(1) increasing the trunk flexion duration
(2) increasing the knee extension duration
(3) increasing the overlap time from beginning of knee extension to the end of trunk flexion (the momentum transfer phase).

To test this, we tested PwMS with 3 wearable MEMS inertial sensor nodes on the sternum (1 node) and thighs (1 node on each thigh), and compared the results to healthy, age-matched volunteers.

2 METHODS

2.1 Participants

12 PwMS were recruited from a local community MS centre (MS Sussex). 11 healthy volunteers were recruited via the University of Brighton. The experimental procedure was approved by the tier two university ethics committee (University of Brighton). Each participant was fully informed about the nature of the experiment and gave written consent.

2.2 Sensors

Inertial wearable sensor nodes (NGIMU, x-io sensors, Bristol, UK) were used for ambulatory assessment. Each node is in a single plastic housing and records nine channels of inertial data, three each of gyroscopy, accelerometry, and magnetometry. The sensors are factory calibrated. Each NGIMU sensor inertial channel was recording at a sampling rate of 100 Hz. Data acquisition was synchronised by concurrent recording of individual sensor signals via wifi according to the standardized software from the manufacturer; a master and slave protocol was used to keep all sensors synchronised to the same clock. Data was recorded into comma separated variable files (csv) which were imported into Matlab and analysed using purpose-made scripts [7].

2.3 Tasks

2.3.1 T25FW. The T25FW was conducted based on the MS functional composite guidelines. Participants were asked to walk along a 25-foot course "as quickly as possible, but safely". Timing was recorded using a handheld stopwatch. The starting point was marked by the right foot crossing the start line, and the endpoint was when the participant crossed the finish line.

2.3.2 Sit-to-Stand Transition. A chair of standard height (43.5 cm) with no arms was used. The participant was instructed to fold their arms across their chest and sit in the middle of the chair with their back touching the back of the chair. They were advised to keep their legs shoulder width apart. Each individual was then counted down from three and asked to stand up "as fast and as safely as possible" on the word 'Go' and stay standing in an upright position for 3 seconds. The start of the task was defined by the trunk leaving the back of the chair (initial point of trunk flexion), and the end of the task is marked by the participant in a fully erect position. The task was first demonstrated by the researcher before being performed by the participant [5, 7].

2.3.3 Knee Extensor Strength Test with Dynamometer. A handheld dynamometer was used to measure isometric knee extension muscle strength. The participant was sat comfortably and safely on a table with the height adjusted so that their feet were slightly above the floor. The dynamometer was applied directly to the distal anterior surface of the tibia, 4 cm proximal to the ankle joint. Each participant was then asked to apply maximum force as fast and as hard as possible, which was opposed by the researcher. Muscle strength measurements were repeated twice on each leg before performing the Si-St transitions.

2.4 Experimental Protocol

Before the start of the experiment, all participants were briefed on the nature of the study and completed background questionnaires including a demographics form, the multiple sclerosis walking scale (MSWS-12). Participants were subsequently fitted with three sensors in a safe and noninvasive manner [7]. All sensors were worn over clothing and held in place with Velcro elasticated straps and orientated with the X-axis pointing superiorly (proximally). The sensors were placed in the following locations (using elasticated straps and a fabric harness):

- Lateral aspect of left and right thigh (most distal part of sensor 5 cm above the superior border of patella)
- Body of sternum

Participants performed the Sit-to-Stand task twice. They performed the Timed 25 Foot Walk twice after performing a practice run.

2.5 Analysis and Statistics

Because sternum sensors fitted with a harness never precisely accord with the orientation of the body, we used the magnitude measurements combining the three gyroscope channels of the sternum node together to represent total rotational activity:

$$G_{magnitude} = \sqrt{G_x^2 + G_y^2 + G_z^2}$$

Movement data acquired with the IMU sensors did not follow a normal distribution. Therefore, a nonparametric Mann Whitney U test was performed in order to analyse the differences between the healthy control group and PwMS. Effect sizes for the nonparametric tests were measured using the Cliff's delta (δ) statistic. The strength of association between various factors in this study was analysed by using Spearman's rank correlation coefficients due to the monotonic relationship between different variables.

3 RESULTS

3.1 Basic Performance Values of Cohort

There was no significant difference in age, height, weight, or BMI between PwMS and healthy controls (p=0.109, p=0.254, p=0.878, and p=0.242, respectively). All the strength measurements comparing healthy to PwMS were significantly different, including the stronger leg (p=0.011, Cliff's $\delta = 0.636$), the weaker leg (p=0.012, $\delta = 0.629$), the combined strength of both legs (p=0.009, $\delta = 0.652$). and weight-normalised combined strength (p=0.029, $\delta = 0.545$). As expected, performance of the T25FW between healthy and PwMS was significantly different (p=0.004, $\delta = 0.712$), as was the MSWS-12 patient reported outcome (p<0.001, $\delta = 0.962$). When the healthy participants and the PwMS were considered as one cohort, the T25FW performance time was correlated to normalised knee extensor strength (Spearman's $\rho = -0.66$, p<0.001) and also to the MSWS-12 values ($\rho = 0.727$, p<0.001).

3.2 Measuring Si-St with Sensors

Figure 2 shows the representative traces during the Si-St transition for a healthy participant. Time point A (black vertical dotted line) is the start of the impulse phase of the sternum gyroscope magnitude trace (solid light blue line). Point B (vertical dotted line) is the start of the rotation of the thigh (including extension of the knee) as seen on the thigh's pitch gyroscope trace (dashed dark blue). The local minimum at point C (vertical dotted) is the reversal of the torso's rotation from flexion to extension; this point is the end of the momentum transfer phase and the start of the extension phase. In this healthy participant point C is synchronous with a local minimum in the thigh pitch gyroscope trace related to seat off (thigh). Point D is the end of the thigh's rapid rotation; activity after this point represents the stabilisation phase. The duration of the phases of Si-St are shown with horizontal dotted lines with double headed arrows. A to C is the impulse phase, B to C is the momentum transfer phase (which overlaps with both the impulse and dorsiflexion stages) and C to D is the extension phase. The arrowhead P1 is the peak of the impulse activity of the sternum, P2 is the peak of the thigh's rotation, and P3 is the peak of the extension phase of the sternum.

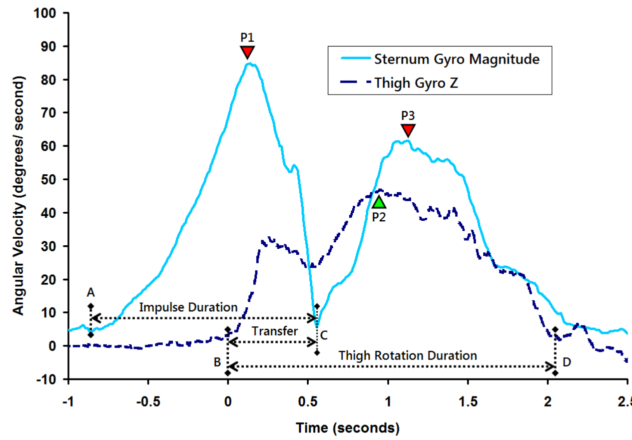

Figure 2: Representative traces of sternum node gyroscopy magnitude vs. thigh pitch gyroscope during sit-to-stand

As expected, the peak value of the thigh's rotation (height of P2) was correlated with normalized knee extensor strength ($\rho = 0.768$, p<0.001), and inversely correlated with subjective disability (MSWS-12, Spearman's $\rho = -0.490, p = 0.017$), walking performance (T25FW duration, $\rho = -0.670, p < 0.001$), and thigh rotation duration ($\rho = -0.839, p < 0.001$). The impulse peak of the sternum was likewise inversely correlated with its duration ($\rho = -0.762, p < 0.001$), MSWS-12 ($\rho = -0.435$, p=0.038), and T25FW ($\rho = -0.402$, p=0.058), but less so than the thigh peak. Interestingly, there was a stronger anti-correlation between the peak of the thigh's rotation and the duration of the sternum's impulse ($\rho = -0.710, p < 0.001$) than its correlation with the sternum's peak ($\rho = 0.577$, p<0.001). This suggests that individuals who had weaker knee extensor performance may strategically extend their momentum transfer phase in order to ease the burden on the thigh extensors. This supports the fact that the duration of the momentum transfer phase (on Figure 2 between points B & C) was strongly anti-correlated with the thigh's peak rotation ($\rho = -0.700$, p<0.001). On average, the PwMS cohort had significantly longer momentum transfer phases than the healthy participants (p=0.039, $\delta = 0.515$, see Figure 3)

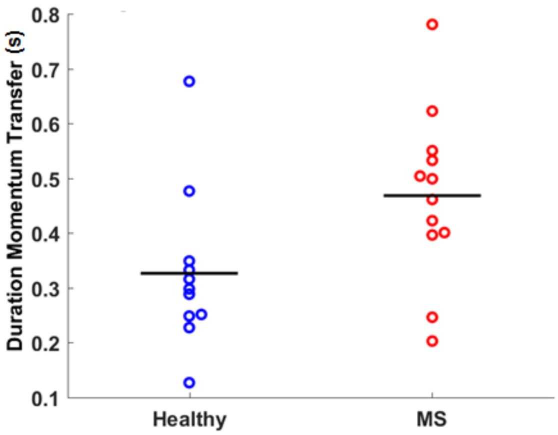

Figure 3: Duration of Momentum Transfer Phase: Healthy vs. MS

4 DISCUSSION

This study explored the use of NGIMU sensors affixed to multiple body segments in the identification and analysis of different kinetic and kinematic features of the Si-St transition in PwMS in comparison to healthy controls. This methodology could be a complementary approach in assessing disability in MS along with existing subjective and objective clinical measures (eg. MSWS-12 and T25FW, respectively). It was found that sensor-based Si-St analysis using multiple sensors was effective in the detection of discriminatory kinematic features, distinguishing individuals with MS exhibiting clinical disability at various anatomical regions rather than just a single one. In particular, the duration of the momentum transfer phase of Si-St (the overlap of the impulse activity of the sternum with the rotational activity of the thigh) was increased in weaker performances of the Si-St, especially for multiple sclerosis.

The placement of NGIMU sensors on the lateral aspects of the thigh facilitated the capture of the kinematics of the thigh and knee joint during the transition in PwMS and healthy controls [7]. NGIMU sensors fixed at the sternum permitted analysis of the kinematics of trunk movements in PwMS and healthy controls during the impulse phase and comparison with thigh kinematics in order to better understand the biomechanics of the Si-St transition. Gyroscope magnitude offered a measure of net exertion of movement which accounted for the malpositioning of the sternum sensor due to size of chest or presence of breasts. Peak angular velocity derived from gyroscope magnitude at the sternum sensor was lower in PwMS when compared with healthy controls, implying a weaker effort at the trunk. This has been suggested to be a cognitive choice rather than a limitation of the trunk. A momentum transfer strategy may lead to the risk of falling forward in PwMS who do not have sufficient balance or muscular control [6]. Various sensor-based parameters derived from the thigh pitch trace during the Si-St transition, including peak angular velocity and thigh rotational duration revealed significant differences between the two cohorts. PwMS also exhibited a greater deficit in normalized lower limb muscle strength in relation to healthy controls. An inverse relationship between normalised strength and duration of the thigh rotation was indicative of the importance of quadriceps strength in overcoming inertia and completing the Si-St movement quickly and successfully [2].

Cognitively in Si-St there is a trade off between *positioning* and *movement* of the torso to a flexed position to achieving seat-off. A greater overlap of trunk movement at the end of the impulse phase with the initiation of thigh movements, as seen in PwMS in this study, represents a *trunk flexion strategy*. This strategy is slower than using momentum transfer to achieve seat off, but it has fewer risks for loss of control and falling forward. However, it increases the durations of both trunk flexion and knee extension in order to compensate for reduced strength and control of knee extension [2, 3]. Previous studies have demonstrated that in healthy persons the impulse phase is sharper and faster, effectively ending before the rapid phase of thigh rotation [4, 5].

4.1 Conclusions

This study has illustrated the differences in Si-St strategies in use when knee flexor muscles are weak, such as in multiple sclerosis. This study has also demonstrated the value of placing an inertial sensor on the thigh to complement traditional sensor placement on the torso for providing an accurate and unequivocal depiction of the kinematics of the Si-St transition. Future research with additional sensor placements (e.g. the ankle and shoe) is needed to fully describe the subphases of the demanding momentum transfer phase of Si-St, and to categorise different strategies that people use to achieve this task.

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REFERENCES

[1] Lance M Bollinger, Michelle C Walaszek, Rebekah F Seay, and Amanda L Ransom. 2019. Knee extensor torque and BMI differently relate to sit-to-stand strategies in obesity. *Clinical Biomechanics* 62 (2019), 28–33.
[2] Bradley Bowser, Sean O'Rourke, Cathleen N Brown, Lesley White, and Kathy J Simpson. 2015. Sit-to-stand biomechanics of individuals with multiple sclerosis. *Clinical Biomechanics* 30, 8 (2015), 788–794.
[3] Caroline AM Doorenbosch, Jaap Harlaar, Marij E Roebroeck, and Gustaaf J Lankhorst. 1994. Two strategies of transferring from sit-to-stand; the activation of monoarticular and biarticular muscles. *Journal of Biomechanics* 27, 11 (1994), 1299–1307.
[4] Gunilla E Frykberg and Charlotte K Häger. 2015. Movement analysis of sit-to-stand–research informing clinical practice. *Physical Therapy Reviews* 20, 3 (2015), 156–167.
[5] Yu Rong Mao, Xiu Qin Wu, Jiang Li Zhao, Wai Leung Ambrose Lo, Ling Chen, Ming Hui Ding, Zhi Qin Xu, Rui Hao Bian, Dong Feng Huang, and Le Li. 2018. The crucial changes of sit-to-stand phases in subacute stroke survivors identified by movement decomposition analysis. *Frontiers in Neurology* 9 (2018), 185.
[6] Donna M Scarborough, David E Krebs, and Bette A Harris. 1999. Quadriceps muscle strength and dynamic stability in elderly persons. *Gait & Posture* 10, 1 (1999), 10–20.
[7] Harry J Witchel, Cäcilia Oberndorfer, Robert Needham, Aoife Healy, Carina EI Westling, Joseph H Guppy, Jake Bush, Jens Barth, Chantal Herberz, Daniel Roggen, et al. 2018. Thigh-derived inertial sensor metrics to assess the sit-to-stand and stand-to-sit transitions in the timed up and go (TUG) task for quantifying mobility impairment in multiple sclerosis. *Frontiers in Neurology* 9 (2018), 684.