Research into Spinal Deformities 12
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doi:10.3233/SHTI260742

Upper Thoracic Segmental Acceleration Time-Series Analysis of Trunk Control During Sit-to-Stand in Adolescent Idiopathic Scoliosis: A Novel Individual-Level Analytical Approach

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Abstract. Adolescent idiopathic scoliosis (AIS) can alter movement strategies during functional tasks such as sit-to-stand (STS), yet sensitive biomechanical measures capable of detecting subtle motor control adaptations remain underexplored. This preliminary study examined phase-specific upper thoracic (UT) segment acceleration during STS before and after a one-week intensive Schroth exercise intervention in individuals with AIS. Seven adolescents with AIS (five female, two male; mean age 15.43 ± 2.37 years) underwent pre- and post-intervention three-dimensional motion capture during a standardised STS task. Peak UT accelerations and phase durations were extracted for the horizontal and vertical phases of the movement. Group-level vertical acceleration demonstrated the most substantial change, increasing from 1.81 m/s/s (SD 0.31) to 2.25 m/s/s (SD 0.40) post-intervention. Horizontal acceleration also increased (1.32 to 1.60 m/s/s), while phase durations remained broadly similar. Considerable inter-individual variability was observed, with P1 and P6 showing the most pronounced acceleration gains. Phase-specific UT acceleration analysis provides a sensitive and clinically informative means of detecting acute movement adaptations following Schroth therapy in AIS. Single-subject waveform analysis further highlights the potential of this approach for individualised intervention monitoring, warranting investigation in larger cohorts. These findings suggest that UT acceleration based STS assessment may offer clinicians a practical and objective tool for tracking neuromuscular responses to conservative scoliosis management in real-world rehabilitation settings.

Keywords. Adolescent idiopathic scoliosis, Schroth therapy, sit-to-stand, upper thoracic acceleration, motor control

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1. Introduction

Adolescent idiopathic scoliosis (AIS) is a spinal deformity that can affect dynamic movement and postural stability, thus impacting on an individuals' ability to perform activities of daily living. A common task is the sit-to-stand (STS) movement, which has been shown to be an effective assessment of motor control and functional independence in clinical scenarios [1].

Recent empirical data on the STS task implies that individuals with AIS have similar thoracic range of motion (ROM) during the STS transition compared to matched controls [2]. While ROM has traditionally been used to evaluate trunk movement during STS, it provides limited insight into the timing and quality of movement control. In addition, since the STS task requires the generation and control of momentum in a very short period, a more sensitive outcome measure such as acceleration may identify subtle alterations in motor control strategies.

This preliminary study introduces a phase-specific and time-series analysis of upper thoracic (UT) acceleration as a novel technique to evaluate movement adaptations before and after a one-week Schroth exercise intervention in individuals with AIS. This approach provides a refined means of assessing postural control and segmental coordination during STS. Furthermore, a focus on acute movement adaptations of individual participants via single-subject analysis has potential applications in both clinical assessment and intervention monitoring.

2. Methods

This observational cohort study examined adolescents with idiopathic scoliosis undergoing intensive Schroth therapy at a residential rehabilitation camp. Ethical approval was obtained prior to data collection, and informed consent and assent was provided by all parents and participants. Seven individuals (five female, two male) with a confirmed diagnosis of AIS were recruited, with a mean age of 15.43 years (SD = 2.37), mean height of 168 cm (SD = 5.73), and mean body mass of 56 kg (SD = 12.54).

Pre- and post-intervention kinematic data were collected using a ten-camera motion capture system (Vicon, Oxford, UK) sampling at 100 Hz. Reflective markers were positioned on the spine, pelvis, and lower limbs in accordance with the protocols described by Needham et al. [3,4]. Participants performed the sit-to-stand task from an armless chair set at a standardised height, with feet positioned shoulder-width apart, knee flexion at 90°, and the trunk maintained in a vertical orientation with arms folded across the chest. Familiarisation trials were administered prior to data collection until consistent task execution was observed [1]. Data was collected immediately before and following completion of the camp.

The intervention comprised a five-day intensive Schroth therapy programme delivered by certified therapists, incorporating supervised individual and group sessions targeting postural correction, rotational breathing, and neuromuscular control (approximately four hours per participant per day).

Phase durations, peak accelerations, and acceleration time-series waveforms were extracted for the upper thoracic segment (UT) defined by global motion of a 3D cluster attached over T3 vertebrae along the anterior-posterior and vertical axes. Three trials were collected during each testing session.

3. Results

Phase durations showed moderate changes following the Schroth intervention. Horizontal phase time decreased slightly from a group mean of 0.97s (SD 0.13) to 0.90s (SD 0.10), while vertical phase duration remained virtually unchanged at 1.21s (SD 0.21) pre-intervention and 1.22s (SD 0.14) post-intervention. More pronounced changes were observed in upper thoracic segment acceleration. Horizontal acceleration increased from a group mean of 1.32 m/s/s (SD 0.23) to 1.60 m/s/s (SD 0.41), while vertical acceleration demonstrated the most substantial change across all measures, rising from 1.81 m/s/s (SD 0.31) to 2.25 m/s/s (SD 0.40). At the individual level, P1 emerged as the strongest responder, demonstrating the largest gains in both horizontal (1.31 to 2.36 m/s/s) and vertical (1.51 to 2.51 m/s/s) acceleration. P6 recorded the highest post-intervention vertical acceleration in the dataset (2.84 m/s/s), while P7 showed a meaningful vertical acceleration improvement (1.70 to 2.24 m/s/s). Conversely, P2 and P4 demonstrated more modest responses, with P2 showing negligible change in horizontal acceleration (1.22 to 1.19 m/s/s) and P4 recording the lowest post-intervention vertical acceleration among improvers (2.09 m/s/s) (Table 1).

Across participants, the time-series waveforms follow a broadly consistent biphasic pattern, with an initial UT acceleration peak corresponding to the horizontal phase, followed by a second peak during the vertical phase, before signals decay toward baseline as standing is achieved (Figure 1). Both horizontal and vertical acceleration waveforms generally mirror this structure, though with notable inter-individual differences in magnitude, timing, and the effect of intervention. In several participants, post-intervention waveforms (grey lines) show increased peak UT accelerations compared to pre-intervention (black lines), consistent with the group-level acceleration increases reported in Table 1. For example, this is most visually apparent in P1 and P6, where post-intervention vertical acceleration peaks are notably higher and the waveform shape appears more defined, suggesting a more forceful and coordinated movement pattern. P3 also demonstrates visible increases in both planes post-intervention.

Table 1. Phase duration and upper thoracic segment peak acceleration during the sit-to-stand task, pre- and post-Schroth intervention, for each participant with group mean and standard deviation.

			Phase time (s)				UT segment acceleration (m/s/s)			
			Horizontal		Vertical		Horizontal		Vertical	
	Gender	Schroth Classification	Pre	Post	Pre	Post	Pre	Post	Pre	Post
P1	Female	TleHri	1.08	0.87	1.08	1.24	1.31	2.36	1.51	2.51
P2	Female	TleHri	1.08	0.86	1.32	1.18	1.22	1.19	1.62	1.64
P3	Male	TriHle	0.88	0.76	1.40	1.17	1.74	1.91	2.01	2.48
P4	Female	LleHTri	0.85	0.83	1.18	1.12	1.27	1.31	1.55	2.09
P5	Male	LleHTri	1.13	1.06	1.27	1.43	0.98	1.43	1.90	1.93
P6	Female	TriHSle	0.99	1.08	1.39	1.38	1.44	1.34	2.37	2.84
P7	Female	LriHTleSri	0.81	0.87	0.81	1.02	1.27	1.65	1.70	2.24
Mean			0.97	0.90	1.21	1.22	1.32	1.60	1.81	2.25
SD			0.13	0.12	0.21	0.14	0.23	0.41	0.31	0.40

UT = upper thoracic; SD = standard deviation; Pre = pre-intervention; Post = post-intervention. Schroth classification codes: T = thoracic; L = lumbar; H = hip; S = sacral; le = left elevation; ri = right elevation.

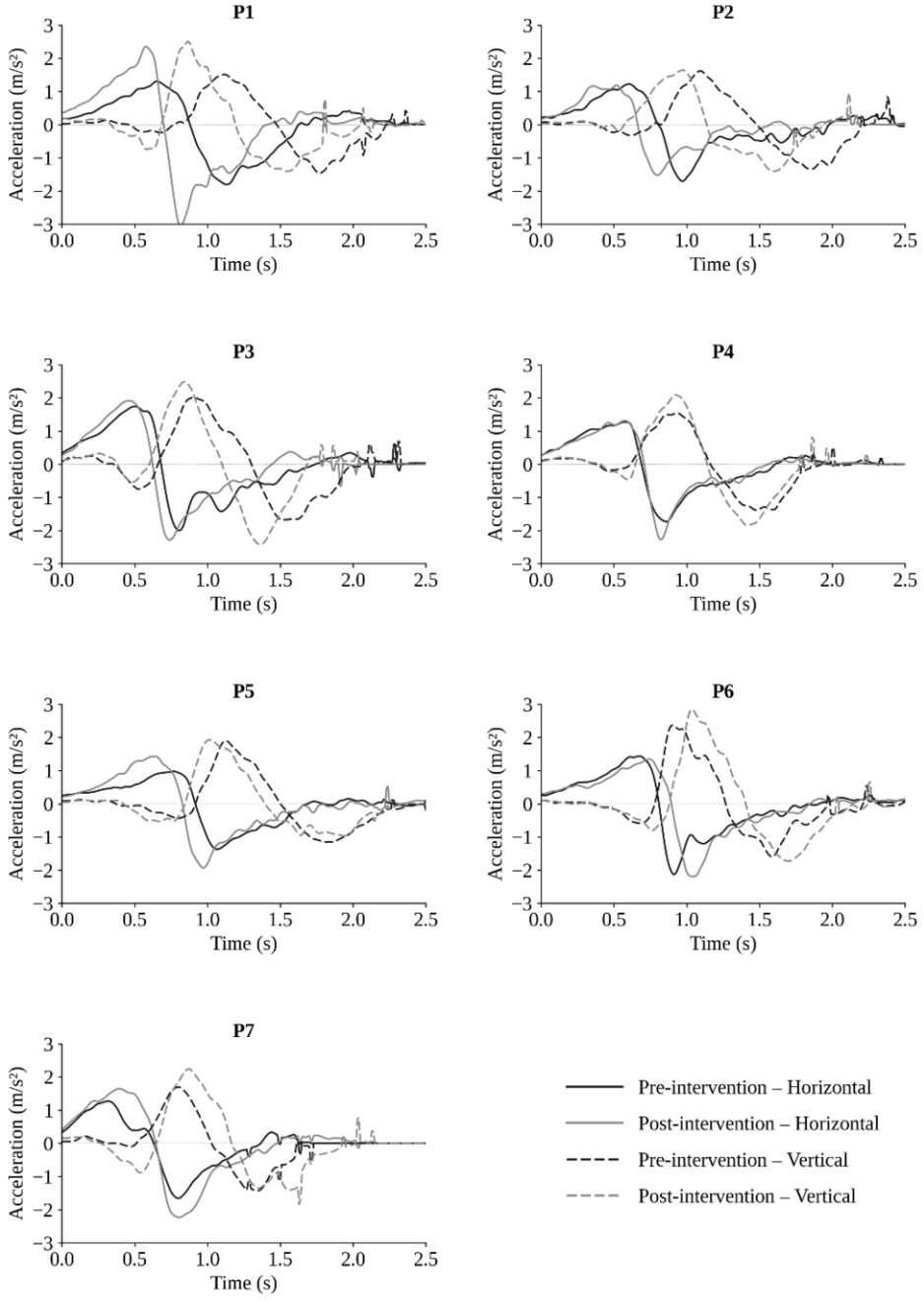


Figure 1. Figure 1. Mean upper thoracic segment acceleration (m/s²) time-series waveforms during the sit-to-stand task for each participant (P1–P7), recorded pre- and post-Schroth intervention. Solid lines represent horizontal (anterior-posterior) acceleration and dashed lines represent vertical acceleration. Black lines indicate pre-intervention data and grey lines indicate post-intervention data.

4. Discussion

This preliminary study examined phase-specific UT segment acceleration during the STS task before and after a one-week intensive Schroth intervention in adolescents with AIS. The principal finding was a group-level increase in UT acceleration, particularly in the vertical plane, alongside broadly preserved phase durations, suggesting that the intervention facilitated more forceful and coordinated trunk movement without substantially altering movement timing.

During the vertical phase of STS, the trunk must decelerate and stabilise as the individual transitions to full standing, a process requiring effective neuromuscular control of the thoracic segment. Greater post-intervention vertical UT acceleration may reflect improved trunk muscle activation and segmental coordination. Therefore, this may be consistent with the neuromuscular retraining emphasis of the Schroth method, which targets rotational breathing, postural correction, and active muscular stabilisation of the scoliotic curve. The relative stability of phase durations across the intervention further suggests that these acceleration changes represent qualitative improvements in movement execution rather than simply faster performance.

The time-series waveform analysis provided additional insight beyond discrete peak values. The more defined biphasic waveform observed post-intervention in several participants, most notably P1 and P6, suggests a more organised and forceful movement strategy, characterised by cleaner acceleration and deceleration profiles. This contrasts with the more attenuated or irregular waveforms seen in limited responders such as P2, highlighting the potential of waveform analysis to capture individual movement quality in ways that group means cannot.

Considerable inter-individual variability in response was evident, which is perhaps anticipated given the heterogeneous nature of AIS and the differing Schroth classifications across participants. P1 and P6 demonstrated the most pronounced adaptations, while P2 and P4 showed comparatively modest changes. Such variability highlights the importance of single-subject analysis in this population and suggests that classification-specific or curve-pattern-specific responses to intervention may warrant further investigation.

Several limitations should be acknowledged. The small sample size and absence of a control group preclude definitive conclusions regarding intervention efficacy, and the one-week timeframe limits insight into longer-term adaptation. Nevertheless, this study demonstrates the feasibility and sensitivity of phase-specific UT acceleration analysis as a clinical outcome measure, with potential applications in monitoring individual responses to conservative scoliosis management.

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