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Physical activity measurement through accelerometry during group tele-exercise in individuals with spinal cord injury: A case series

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Nearly 50% of individuals with spinal cord injury (SCI) are inactive which increases risk for chronic disease and early mortality. Our team previously developed an online group exercise program that is safe, feasible, based on SCI exercise guidelines, and directly responsive to needs and requests of individuals with SCI. The goal of this study was to evaluate the feasibility of measuring physical activity exertion through a digital smartwatch during the tele-exercise class. We measured how much time participants spent in moderate-vigorous physical activity exertion during class to meet national physical activity guidelines for health.

Keywords: *Spinal cord injury; exercise; health; physical activity; wearable device*

Introduction

Regular physical activity is a modifiable behavior that is critical to health maintenance for individuals with spinal cord injury (SCI).[1–4] However, nearly half of individuals living with SCI are sedentary which expedites the development and progression of several secondary health conditions including obesity, cardiopulmonary disease, osteoporosis, heterotopic bone development, pressure ulcers, sleep disorders, and chronic pain.[5] The development and measurement of novel strategies to promote physical activity participation in this population are needed to remedy these health risks. Our team previously developed Tele-Exercise to promote Empowered Movement in SCI (TEEMS), a group program responsive to physical activity access barriers that individuals with SCI experience.[6,7] The program is informed by available exercise guidelines for SCI which emphasize aerobic and strength training to achieve moderate-vigorous physical activity (MVPA) intensity to meet national guidelines for health maintenance.[1,8] Program participation shows promising improvements in physical activity behavior over time[9], but evaluation of during TEEMS is warranted to determine intraclass exertion.[10]

Previously available evidence for physical activity tracking in this population has relied on self-report measures. Self-report measures are subject to response variability, often relating to participant overestimation of behavior.[11] Additionally, health fluctuations with SCI can change self-report as exacerbation of secondary health conditions influence physical activity behavior[1211].[13,14] Further, validated SCI-specific physical activity self-report outcome measures demonstrate within-subject variability for leisure-time physical activity recall.[9,15] Assessment of physical activity using biophysical measures is important to understand effects of evidence-based interventions aimed at changing this health behavior.

Accelerometry via wearable wrist-worn Actigraph monitors is a viable biophysical measurement method for physical activity tracking in individuals with SCI (fig 1).[16] The device is the size of a smartwatch and allows for ease of access and remote data collection set up.

Figure 1: Wrist-worn Actigraph device

Accelerometry has been used in combination with machine learning models to measure physical activity in this population.[17] Accelerometry has been validated to estimate energy expenditure in individuals with SCI and been compared to validated self-report outcomes such as the Physical Activity Recall Assessment (PARA-SCI).[18–20] Additionally, this method has been integrated into community-based adaptive interventions to provide real time feedback based on physical activity behavior.[21]

With a growing evidence base, the energy expenditure predictions for this population based on accelerometry are few and show varying outputs. This indicates additional work is needed to evaluate physical activity tracking with accelerometry in individuals with SCI and examine additional algorithms to monitor behavior. The Monitor-independent movement summary (MIMS-unit) is an open-source algorithm created to summarize high-resolution raw accelerometry data to estimate physical activity behavior by counts.[22] MIMS-unit allows for assessment of physical activity based on individual perception of exertion. MIMS-unit has characterized total physical activity volume using United States population data[23] and determined an association between movement and cognitive function in older adults.[24] While MIMS-unit offers a potential method to estimate physical activity in individuals with SCI, available evidence for its use in this population warrants further investigation. The purpose of this exploratory study was to describe MVPA behavior during TEEMS program participation using accelerometry and MIMS-unit algorithm. A secondary self-reported exertion rating (RPE) was collected as an acceptable assessment of MVPA in adults with SCI.[25]

Materials and Methods

Participants with chronic SCI (>12 months) volunteered for a non-randomized registered clinical trial [NCT05360719]. The study was approved by the XXXXX Institutional Review Board. The clinical trial evaluated Tele-Exercise to promote Empowered Movement in individuals with SCI (TEEMS), a synchronous group tele-exercise program. TEEMS is designed to strengthen personal factors critical to lifelong physical activity behavior by overcoming barriers to exercise participation in individuals with SCI.[9] This is achieved through distanced delivery (tele-exercise), expert instruction (co-leadership by a rehabilitation clinician and individual with SCI), peer engagement (group-based learning) and orientation to self-management strategies (goal setting, perceived exertion monitoring, exercise practice).

TEEMS program length, frequency, and duration were informed by exercise guidelines for adults with SCI.[8] TEEMS met biweekly via web communication software over 8-weeks (16 total sessions). Each 60 minute class included a 15 minute discussion and 45 minutes of exercise broken into segments: warm up, shoulder and trunk stability, aerobic training, strength training, and cool down (Figure 2). Additional details on the intervention, its feasibility, and initial outcomes are published elsewhere.[7,9,10]

Component	Description
Segment 1	Welcome and group discussion
Check-in	Diaphragmatic breathing
	Meditation
Segment 2	Neck mobility
Warm-up, 5 min	Shoulder mobility
	Spinal mobility
	Elbows/wrist mobility
Segment 3	*Done in 3 exercise circuits 5 min each*
Cardiovascular	1. Arm jacks
training, 20 min	1. Marches
	1. Cross-body reach
	2. Overhead reach
	2. Side reach
	2. Low reach
	3. Cross Jab
	3. Uppercut
	3. Hook
	3. Speed bag
Weights, 15 min	*Bilaterally or unilaterally with trunk stabilization*
	3 sets of 8
	1. Shoulder shrugs
	2. Lateral raise
	3. Bicep curls
	4. Shoulder press
	5. Rows
	6. Halos
	7. Chops
Cooldown, 5 min	Neck stretches
	Shoulder stretches
	Spinal stretches
	Deep breathing
Checkout	Class reflection
	Goodbyes

Figure 2: TEEMS Class Exercise Checklist

A subset of participants were sent Actigraph GT3X+ accelerometers by mail in Week 6 of the program. [17]Accelerometry data were collected during two comparable 45-minute sessions of the TEEMS program during Week 6-7 for all participants. This data collection timeline was chosen to minimize response variability due to unfamilairy with the program. Participant instructions for accelerometry data collection were completed using a previously established remote protocol.[17] Actigraphs were set up to collect accelerometry data at 60 Hz sampling rate over a 5-day period to capture desired data during class sessions (usually 48 hours apart). Participants were instructed to record their average perceived exertion using the Rate of Perceived Exertion (RPE) scale, an acceptable measure to assess MVPA for adults with SCI,[25] after each class segment in their program exercise logbook. These included warm up, stability, 3 aerobic circuits, strength, and cool down sections. Self-report of MVPA was determined through individual RPE ratings of "somewhat hard" (RPE $\geq$ 13/20). Participants returned their Actigraph and RPE ratings by mail. Data processing was completed using MIMS-unit[22] which converted raw accelerometry data to summarized acceleration units. Data was manually cleaned to remove MIMS-unit readings outside of the two specified TEEMS class durations. Individual participant RPE ratings of 13/20 or above were linked to timed class segments to establish moderate exertion cutoff for MIMS-unit counts during the exercise sessions. Average MIMS-units for each class segment were calculated by individual participant.

Results

Six adult participants (biological sex: males=2, females=4, average age: 46$\pm$14.0 years) with chronic SCI (injury duration 7-48 years) volunteered and completed the study. Participants reported either cervical (n=2) or thoracic (n=4) level injuries. Participants were classified as active or inactive at enrollment based on responses to the American College of Sports Medicine (ACSM) Pre-participation Health Screening.[26] Please see table 1 for additional demographic details.

Table 1.
Demographic features of participants

ID	Exercise status	Sex assigned at birth	Age (years)	Age at injury (years)	Injury duration (years)	Injury level	Injury severity	Injury cause
A	Active	Male	47	40	7	Thoracic	Complete	MVA
B	Inactive	Female	45	32	13	Cervical	Incomplete	Fall
C	Inactive	Female	65	18	48	Thoracic	Incomplete	MVA
D	Inactive	Female	26	18	7	Thoracic	Complete	GSW
E	Active	Female	57	29	28	Cervical	Incomplete	MVA
F	Active	Male	36	25	11	Thoracic	Complete	MVA

Exercise status determined by American College of Sports Medicine (ACSM) Exercise Readiness Questionnaire
Injury cause: MVA = Motor vehicle accident, GSW = Gunshot wound

Please see table 2 for MIMS-units and RPE ratings by individual participant for each class segment. Participants met or exceeded threshold for MVPA exertion in stability, cardiovascular, and strength training class segments. A trend across all participants emerged demonstrating highest average MIMS-units during cardiovascular training class segments, followed by stability and strength training. Warm up and cool down segments did not achieve threshold for MVPA, demonstrating lowest MIMS-units. Group cutoff scores were not calculated as this study utilized an exploratory sample size for descriptive purposes and usability of MIMS-unit algorithm.

Table 2.
MIMS-units and RPE by class segment

ID	Measure	Warm up	Stability	Cardio A	Cardio B	Cardio C	Strength	Cool down
A	MIMS	17.40	26.2	112.2	74.9	114.1	22.88	14.6
	RPE	6.0	13.5	15.0	12.5	14.5	14.0	6.5
B	MIMS	17.47	19.0	81.3	80.7	75.0	26.30	16.9
	RPE	7.0	14.0	15.0	15.5	15.0	19.0	7.5
C	MIMS	16.24	29.8	63.2	50.0	56.8	21.54	14.4
	RPE	11.0	16.0	15.5	13.5	16.0	14.0	8.5
D	MIMS	20.68	25.6	112.0	100.1	153.2	22.84	18.0
	RPE	9	14.0	13.0	12.5	12.5	13.5	11.0
E	MIMS	17.65	17.4	62.5	68.1	52.3	17.54	164
	RPE	8	14.5	15.5	18.0	17.0	14.0	8.5
F	MIMS	22.88	26.7	96.7	88.0	84.8	24.8	22.4
	RPE	9.5	12.5	11.5	13.0	13.0	13.5	9.5

RPE scores highlighted represent self-perceived MVPA.

Discussion

Our findings indicate that the use of wearable devices to collect accelerometry data during group tele-exercise in individuals with SCI is feasible and appropriate. This is an important first step to increasing the number of empirical studies utilizing wearable devices to measure physical activity in this population. A recent systematic review on wearable devices to measure physical activity in individuals with chronic health conditions did not include any studies with individuals with SCI, despite several other neurological conditions represented.[24] Wearable devices to measure physical activity are also integral to the World Health Organization (WHO) approach to digital health which emphasizes adoption of scalable person-centered strategies to mitigate chronic disease.

The goal of concurrent measurement of self-reported (RPE) and accelerometer-based physical activity exertion is to validate intrasession training intensity. RPE as used in the current study could be used to potentially estimate MVPA cutoff scores in a larger sample. However, these cutoffs may be best utilized to estimate aerobic activity since accelerometer-based thresholds are sensitive to movement-based activities and may not capture resistance-based activities in this population. The comparison of a physiological measure to RPE may be helpful to ultimately yield a more sensitive prediction of MVPA through accelerometry.

Additionally, this work indicates that data processing via MIMS-unit algorithm in group tele-exercise with individuals with SCI is applicable. This adds to the growing body of literature indicating that open-source procedures allows for transferability of findings to implementation science settings and to end-users.[20] Since MIMS-unit analysis increases standardization of data cleaning and analysis to estimate physical activity behavior, its transferability across devices has a unique advantage. MIMS-unit should be further explored as a data processing method in future studies to estimate physical activity intensity in individuals with SCI.[20]

This study findings are limited due to an exploratory sample for descriptive and feasibility purposes. Future studies to determine MIMS-unit thresholds and ranges for physical activity intensity should include additional participants. Our study included individuals with SCI with varying exercise readiness. Future studies using accelerometry to estimate exertion during a specific physical activity intervention may want to analyze participants by active and non-active groups for a more specific estimation of intensity by exerciser status. Additionally, personalization of thresholds might allow for more tailored interventions.

Accelerometry-based physical activity tracking during group tele-exercise for individuals with SCI is appropriate. The MIMS-unit algorithm is a viable strategy to process the amount of physical activity and may be used in conjunction with a self-reported exercise intensity rating. This work described intrasession training intensity for group tele-exercise and demonstrates feasibility of accelerometry-based physical activity tracking during group tele-exercise in this population.

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Conflicts of Interest
The authors report no conflicts of interest.

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Statement of Contributions
Dr. Laura Baehr was responsible for design, data collection, data analysis, and manuscript preparation. Dr. Shivayogi Hiremath contributed to design, data analysis and manuscript preparation. Dr. Margaret Finley contributed to design and manuscript preparation.

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