NeuroRehabilitation 55 (2024) 59–68
DOI:10.3233/NRE-240083
IOS Press

Para table tennis improves psychological/mental and cardiovascular health in individuals with spinal cord injury

Hsi-Kai Tsou[a,b,c,d,∗], Hsiao-Yu Chen[e], Kuan-Chung Shih[f] and Yueh-Chiang Lin[g,h]
[a]*Functional Neurosurgery Division, Neurological Institute, Taichung Veterans General Hospital, Taichung, Taiwan*
[b]*Department of Rehabilitation, Jen-Teh Junior College of Medicine, Nursing and Management, Houlong, Taiwan*
[c]*Department of Post-Baccalaureate Medicine, College of Medicine, National Chung Hsing University, Taichung, Taiwan*
[d]*College of Health, National Taichung University of Science and Technology, Taichung, Taiwan*
[e]*Department of Nursing, National Taichung University of Science and Technology, Taichung, Taiwan*
[f]*The Rong Sing Medical Foundation, Taichung, Taiwan*
[g]*Neurological Institute, Taichung Veterans General Hospital, Taichung, Taiwan*
[h]*National Taichung University of Science and Technology, Taichung, Taiwan*

Received 14 April 2024
Accepted 19 June 2024

Abstract.
BACKGROUND: Although rehabilitation exercise is known to be beneficial for cardiovascular and mental health, it remains a daunting challenge for patients with spinal cord injury (SCI) who rely on wheelchairs for mobility.
OBJECTIVE: This study aimed to examine the effectiveness of a 4-week para table tennis program in enhancing self-efficacy and health outcomes in adults with SCI.
METHODS: A total of 39 SCI patients were included and divided into the experimental group ($n = 18$, a 4-week para table tennis training program) and the control group ($n = 21$). Frequency domain indices of heart rate variability (HRV) were used to evaluate the function of the autonomic nervous system.
RESULTS: Following para table tennis training, there was a significant reduction in the physical stress index (PSI, $P < 0.001$), accompanied by shifts in autonomic regulation of vagal dominance. Additionally, the para table tennis training led to significant improvements in vessel state, differential pulse wave index, atrial elasticity, eccentric constriction power, remaining blood volume, and self-efficacy (all $P < 0.05$).
CONCLUSION: Para table tennis training results in favorable changes in sympathetic tone, enhanced self-efficacy, improved cardiovascular well-being, and an overall positive transformation in HRV.

Keywords: Spinal cord injury, wheelchair, para-table tennis, autonomic nervous system, cardiovascular health

∗Address for correspondence: Hsi-Kai Tsou, Functional Neurosurgery Division, Neurological Institute, Taichung Veterans General Hospital, 1650 Taiwan Boulevard Section 4, Taichung, Taiwan 40705, Republic of China. Tel.: & Fax: +886 4 23741218; E-mail: tsouhsikai@gmail.com.

1. Introduction

Spinal cord injury (SCI) is a severe life-threatening disease, often resulting in tetraplegia or paraplegia. Despite advances in medicine, patients with SCI may never regain their original physical functioning and must learn to live with disabilities (Chang et al., 2017; Dolbow et al., 2021), so they may rely on wheelchairs for long-term mobility. According to the Global Burden of Disease Study, the annual incidence of SCI has increased in the past few decades, and the global prevalence in 2019 is approximately 6.2 person per million (Ding et al., 2022). Physiological complications commonly experienced by patients with SCI include neurological disorders, cardiovascular-related disease symptoms, and disorders of the respiratory tract, digestive tract, urinary tract, skeletal muscle, and skin, as well as disturbances in pain and temperature control (Craig et al., 2021; Serra-Añó et al., 2015). In addition to physiological trauma, psychological disorders, such as anxiety and depression, negatively impact people around the patient with SCI (Chen et al., 2012; Le & Dorstyn, 2016; Lim et al., 2017).

The autonomic nervous system is subdivided into sympathetic and parasympathetic nervous systems, which function antagonistically to respond to internal and external perturbations and to maintain homeostasis (Benarroch, 2020; Gibbons, 2019). SCI leads to an imbalance between the sympathetic and parasympathetic nervous systems, which in turn causes long-term sequelae such as cardiac dysrhythmias, systemic hypotension, and uncontrolled bowel dysfunction (Henke et al., 2022). Compared with healthy individuals, patients with SCI often have cardiovascular disorders, weaker sympathetic and parasympathetic activity, decreased arterial elasticity, and lower total power (TP), as well as increased psychological stress evidenced by the physical stress index (PSI) (Malmqvist et al., 2015; Serra-Ano et al., 2015; Tsou et al., 2022).

It has been reported that regular exercise benefits autonomic function in healthy individuals and patients with coronary artery disease (Laing et al., 2011; Manresa-Rocamora et al., 2021), increasing acceptance of their disability and overcome distress and suffering (Ahn et al., 2021; Aitchison et al., 2022). Nevertheless, attention still needs to be paid to strike a balance between appropriate training and adequate rest to avoid cardiac autonomic imbalance due to overtraining (Kajaia et al., 2017), especial in patients with SCI (Buker et al., 2018). Although scientific exercise guidelines suggest that aerobic exercise is recommended for SCI patients to improve cardiorespiratory fitness and cardiometabolic health (Martin Ginis et al., 2018), there is no clear description of the appropriate type and intensity of exercise. Unlike wheelchair rugby or paratriathlon, there are no physical requirements for para table tennis. This study aimed to explore the effects of a 4-week para table tennis training program on self-efficacy, cardiovascular health, stress status, stress resilience, and balance of the autonomic nervous system in individuals with SCI.

2. Materials and methods

2.1. Participants

This study adopted purposive sampling to include individuals, who underwent surgical treatment for SCI and joined a patient support group for SCI for at least one year, from our outpatient clinic between November 2020 and February 2021. The inclusion criteria were as follows: (1) aged 20 to 75, (2) definitive diagnosis of SCI, (3) at least one year after occurrence and treatment of SCI, (4) requiring wheelchairs for mobility, (5) able to carry out daily activities with or without help from caregivers, and (6) occasionally playing wheelchair basketball, para table tennis, and/or wheelchair bowling in the patient support group. Individuals were excluded from this study if they had (1) a history and/or symptoms of cardiovascular disease, (2) severe trauma or surgery within the last six months; (3) inability to use a racket due to upper extremity fracture or paralysis, and (4) cognitive dysfunction or communication difficulties that restricted their ability to participate in the training program. The participants were randomly divided into the experimental group who participated in a 4-week para table tennis training program, and the control group who did not participate in the training program. However, participants who were assigned to the exercise group but were unwilling to participate in the para table tennis training were transferred to the control. The study protocol was approved by the Institutional Review Board of Taichung Jen-Ai Hospital (JAHIRB-109-70) and was conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent prior to participating in the study.

2.2. Study design

All participants in the experimental group underwent 1-h para-table tennis training twice a week, over a period of 4 weeks. The content of training intervention included warm-up exercises, introduction to basic movement and practice such as racket grip, ball trajectory balance training, basic movement training, wheelchair handling skills, forehand practice, backhand practice and continuous hitting, and cool-down exercises. The participants in the control group performed static activities individually for one hour twice a week for 4 weeks. This study followed a quasi-experimental design in which each participant's heart rate variability and arteriosclerosis were obtained through pre- and post-tests. Given the real-world nature of this study, all participants in both groups were asked not to change their usual daily activities, dietary habits, or medications during the study period. After 4 weeks of intervention, all participants completed a self-efficacy questionnaire on the effects of low-intensity para-table tennis training.

2.3. Outcomes and assessments

Heart rate variability (HRV) parameters were obtained before and after low-intensity para table tennis training, including heart rate, standard deviation of NN intervals (SDNN), root mean square of the successive differences (RMSSD), PSI, TP, low frequency (LF), high frequency (HF), very low frequency (VLF), and very high frequency (VHF). The normalized LF was calculated as LF/(TP-VLF) $\times$ 100, and the normalized HF was calculated as HF/(TP-VLF) $\times$ 100. Sympathovagal balance was defined as the ratio of LF to HF (LF/HF). Accelerated photophlethysmography (APG) technology was used to assess the arterial aging in relation to hemodynamics, including vessel state, differential pulse wave index (DPI), eccentric constriction power (EC), atrial elasticity (AE), and remaining blood volume (RBV). Pulse wave velocity (PWV) was extracted from each participant's APG signal using an SA-3000P analyzer to calculate the above parameters (Tsou et al., 2022). Vessel state reflecting vascular age was estimated from the APG signal and classified into 7 grades.(Currie et al., 2019; Tsou et al., 2022) The vascular age gets worse with increasing grade. The psychometric properties of all participants were assessed using the translated Moorong Self-Efficacy Scale (MSES), which rates confidence in performing daily activities on a 7-point Likert scale (Chen et al., 2011). The translated Chinese version of the MSES has been demonstrated to have excellent internal consistency for SCI patients, with a Cronbach's alpha of 0.93 for self-efficacy (Chen et al., 2011).

2.4. Statistical analysis

Continuous data are expressed as mean and standard deviation (SD). Categorical data are summarized as frequencies and percentages. The Wilcoxon signed-rank test was used to statistically examine the differences between the data collected from the pre- and post-tests. Differences between the experimental and control groups were examined using Fisher's exact test or the chi-square test for categorical variables. In addition, the Shapiro-Wilk test was used to assess the normality of continuous data. To examine between-group differences, the t-test was used for normal distributed continuous data, while the Mann-Whitney U test for non-normal distributed continuous data. Statistical significance was defined as a two-tailed P-value less than 0.05.

3. Results

3.1. Patient characteristics

A total of 39 eligible individuals with SCI were included and were randomly divided into the experimental group ($n = 18$) and control group ($n = 21$). Table 1 shows the demographics and clinical characteristics of patients with SCI. The mean age was 52.6 ± 11.4 years, and most participants were male (74.4%). The mean age at injury was 21.6 ± 12.2 years, and the most common cause of SCI was car accident (46.2%), followed by illness (33.3%). There were no statistically significant differences in age, sex, education level, marital status, cause of SCI, location of injury, post-injury time, and severity of injury between the experimental and control groups (all $P > 0.05$).

3.2. Effects of para table tennis training on HRV and arteriosclerosis

Table 2 shows the HRV frequency-domain values of participants in the experimental and control groups before and after 4 weeks of para table tennis

Table 1
Demographics and patient characteristics

Variables	Total ($N = 39$)	Experimental ($n = 18$)	Control ($n = 21$)	p-value
Age, years	52.6 ± 11.4	*52.4 ± 14*	52.7 ± 8.9	0.952
Sex				0.290
Men	29 (74.4%)	15 (83.3%)	14 (66.7%)	
Women	10 (25.6%)	3 (16.7%)	7 (33.3%)	
Education level				0.263
Elementary school	1 (2.6%)	0 (0.0%)	1 (4.8%)	
Junior high school	3 (7.7%)	1 (5.6%)	2 (9.5%)	
High school	20 (51.3%)	9 (50%)	11 (52.4%)	
Two-year junior college	3 (7.7%)	1 (5.6%)	2 (9.5%)	
College	11 (28.2%)	6 (33.3%)	5 (23.8%)	
Postgraduate	1 (2.6%)	1 (5.6%)	0 (0.0%)	
Marital status				0.507
Single	17 (43.6%)	9 (50.0%)	8 (38.1%)	
Married & cohabitation	17 (43.6%)	7 (38.9%)	10 (47.6%)	
Divorced	4 (10.3%)	1 (5.6%)	3 (14.3%)	
Widowed	1 (2.6%)	1 (5.6%)	0 (0.0%)	
Age at injury, years	21.6 ± 12.2	24.9 ± 13.7	18.7 ± 10.3	0.118
Cause of injury				0.607
Car accident	18 (46.2%)	8 (44.4%)	10 (47.6%)	
Fall from a height	7 (17.9%)	4 (22.2%)	3 (14.3%)	
Sports injury	1 (2.6%)	1 (5.6%)	0 (0.0%)	
Illness	13 (33.3%)	5 (27.8%)	8 (38.1%)	
Location of injury†				0.477
Cervical	20 (51.3%)	8 (44.4%)	12 (57.1%)	
Thoracic	16 (41.0%)	8 (44.4%)	8 (38.1%)	
Lumbar	8 (20.5%)	5 (27.8%)	3 (14.3%)	
Sacral	1 (2.6%)	1 (5.6%)	–	
Severity of injury				0.630
Complete Tetraplegia	4 (10.3%)	1 (5.6%)	3 (14.3%)	
Incomplete Tetraplegia	13 (33.3%)	5 (27.8%)	8 (38.1%)	
Complete paraplegia	17 (43.6%)	9 (50%)	8 (38.1%)	
Incomplete paraplegia	5 (12.8%)	3 (16.7%)	2 (9.5%)	

A bold number indicates a statistically significant difference with a p-value less than 0.05. †More than one injury site could be present in the same patient. t test and Mann-Whitney U test were used for continuous variables. Fisher's exact test and the chi-square test were used for categorical variables.

training. For participants in the control group, there were no significant differences between the pre-test and post-test values for all frequency domain variables ($P > 0.05$). In contrast, the experimental group showed significantly increased HR ($P < 0.001$) and TP ($P < 0.001$), while reduced PSI ($P < 0.001$), VLF ($P = 0.038$), and LF ($P = 0.018$) after four weeks of training.

When comparing the pre-test and post-test between the two groups, the pre-test values of any frequency domain variable showed no significant differences between the experimental and control groups. In contrast, post-test values of HR, LF/HF, and LFnu in the experimental group were significantly higher than that in the control group (all $P \leq 0.027$). Furthermore, the post-test value of HF and HFnu in the experimental group was significantly lower than that in the control group (both $P \leq 0.026$).

3.3. *Effects of para table tennis training on elastic properties of arterial system*

Table 3 shows the cardiovascular outcomes of the participants before and after 4 weeks of low-intensity para-table tennis training. No significant differences between pre- and post-test were observed in the control group for PWV parameters, except vessel state ($P = 0.046$). However, for participants in the experimental group, there were significant differences between the pre-test and post-test measures in vessel state, DPI, EC, AE, and RBV (all $P \leq 0.005$).

3.4. *Effect of para table tennis training on self-efficacy*

The self-efficacy of participants in the experimental and control groups was evaluated using the MSES

Table 2
Effects of low-intensity para table tennis training on HRV and arteriosclerosis

Variable		Experimental ($n = 18$)	Control ($n = 21$)	p-value‡
HR				
Pre-test		85.40 ± 13.90	82.48 ± 17.18	0.269
Post-test		90.20 ± 15.10	83.10 ± 11.03	**0.027**
	p-value§	**<0.001**	0.667	
SDNN				
Pre-test		24.12 ± 9.02	28.59 ± 16.89	0.566
Post-test		23.44 ± 10.32	24.31 ± 10.71	0.644
	p-value§	0.188	0.495	
RMSSD				
Pre-test		16.20 ± 7.43	19.62 ± 10.82	0.370
Post-test		15.87 ± 9.20	17.43 ± 8.17	0.235
	p-value§	0.083	0.374	
PSI				
Pre-test		159.38 ± 184.10	176.14 ± 199.94	0.514
Post-test		126.41 ± 148.04	152.95 ± 154.42	0.468
	p-value§	**<0.001**	0.892	
TP				
Pre-test		434.30 ± 377.57	748.19 ± 871.87	0.520
Post-test		625.27 ± 561.92	490.39 ± 370.43	0.562
	p-value§	**<0.001**	0.355	
LF/HF				
Pre-test		2.84 ± 2.52	2.17 ± 1.66	0.361
Post-test		3.15 ± 2.93	1.76 ± 1.14	**0.026**
	p-value§	0.146	0.412	
VLF				
Pre-test		316.02 ± 293.44	378.21 ± 389.99	0.936
Post-test		266.08 ± 280.85	256.38 ± 187.90	0.579
	p-value§	**0.038**	0.355	
LF				
Pre-test		131.75 ± 174.08	255.77 ± 438.98	0.536
Post-test		111.13 ± 149.57	133.24 ± 122.89	0.092
	p-value§	**0.018**	0.539	
HF				
Pre-test		71.81 ± 86.08	114.21 ± 131.87	0.523
Post-test		52.01 ± 61.93	99.70 ± 106.89	**0.012**
	p-value§	**0.001**	0.973	
LFnu				
Pre-test		63.80 ± 18.87	60.54 ± 17.30	0.385
Post-test		66.59 ± 16.74	57.67 ± 16.37	**0.026**
	p-value§	0.099	0.539	
HFnu				
Pre-test		36.00 ± 18.88	39.46 ± 17.30	0.359
Post-test		33.41 ± 16.74	42.40 ± 16.53	**0.026**
	p-value§	0.118	0.517	

Abbreviations: HR, heart rate; SDNN, standard deviation of NN intervals; RMSSD, Root mean square of the successive differences; PSI, physical stress index; TP, total power; LF, low frequency; HF, high frequency; VLF, very low frequency (VLF); LFnu, normalized low frequency; HFnu, normalized high frequency. A bold number indicates a statistically significant difference with a p-value less than 0.05. §Wilcoxon signed-rank test. ‡Mann-Whitney U test.

(scores for each item of the MSES are shown in Supplementary Table 1). For participants in the control group, there was no significant difference in self-efficacy scores between the pre-test and post-test ($P = 0.305$; Table 4). Notably, 4 weeks after training, self-efficacy in the experimental group was significantly improved ($P = 0.003$).

4. Discussion

This prospective study found that 4-week para table tennis training program significantly enhanced HR and TP, while reduced PSI, VLF, and LF in participants with SCI. The current results revealed that para table tennis training improved HRV power and

Table 3
Effects of para table tennis training on elastic properties of arterial system

	Experimental				p-value§	Control				p-value§
	pre-test		Post-test			pre-test		post-test		
Vessel state					**<0.001**					**0.046**
Level 1	0	0.0%	4	22.2%		0	0.0%	1	4.8%	
Level 2	4	22.2%	11	61.1%		11	52.4%	6	28.6%	
Level 3	1	5.6%	1	5.6%		2	9.5%	0	0.0%	
Level 4	11	61.1%	0	0.0%		8	38.1%	14	66.7%	
Level 5	0	0.0%	0	0.0%		0	0.0%	0	0.0%	
Level 6	2	11.1%	2	11.1%		0	0.0%	0	0.0%	
DPI					**0.005**					1.000
High	2	11.1%	4	22.2%		2	9.5%	2	9.5%	
Normal	2	11.1%	13	72.2%		12	57.1%	12	57.1%	
Low	14	77.8%	1	5.6%		7	33.3%	7	33.3%	
EC					**<0.002**					0.110
High	7	38.9%	2	11.1%		2	9.5%	2	9.5%	
Normal	11	61.1%	2	11.1%		8	38.1%	13	61.9%	
Low	0	0.0%	14	77.8%		11	52.4%	6	28.6%	
AE					**<0.001**					0.766
High	1	5.6%	18	100.0%		13	61.9%	13	61.9%	
Normal	13	72.2%	0	0.0%		7	33.3%	8	38.1%	
Low	4	22.2%	0	0.0%		1	4.8%	0	0.0%	
RBV					**0.003**					0.424
High	8	44.4%	2	11.1%		2	9.5%	2	9.5%	
Normal	8	44.4%	1	5.6%		8	38.1%	10	47.6%	
Low	2	11.1%	15	83.3%		11	52.4%	9	42.9%	

Abbreviations: DPI, differential pulse wave index; EC, eccentric constriction power; AE, atrial elasticity; RBV, remaining blood volume. A bold number indicates a statistically significant difference with a p-value less than 0.05. §Wilcoxon signed-rank test.

Table 4
Improved self-efficacy after low-intensity para table tennis exercise

	Experimental	Control	p-value‡
Pre-test	80.56 ± 16.27	82.14 ± 16.68	0.766
Post-test	83.94 ± 17.52	83.71 ± 16.33	0.966
p-value§	**0.003**	0.305	

‡Mann-Whitney U test. §Wilcoxon signed-rank test.

sympathetic output, and decreased their stress index. In addition, para table tennis training improved the elasticity of the arterial system, as most participants in the experimental group had improved vessel state, higher DPI and AE, and lower EC and RBV. Notably, para table tennis training also improved the self-efficacy of individuals with SCI. Taken together, the 4-week para table tennis training program improved psychological and cardiovascular health of SCI patients.

Patients with SCI are more likely to be diagnosed with a mental illness than those without SCI (Budd et al., 2022). In a cross-sectional survey of 443 SCI patients in Victoria, Australia, nearly half of SCI patients had experienced mental health problems, including depression, anxiety, clinical-level stress, and post-traumatic stress disorder (Migliorini et al., 2008). A study of 102 patients with SCI revealed that approximately half of SCI patients experienced clinically relevant depressive symptoms immediately post-discharge (Schönenberg et al., 2014). Similar results were also observed in a nationwide population-based cohort study of Taiwan's National Health Insurance Research Database, in which SCI patients had a significant 1.33-fold increased risk of depression or anxiety compared with healthy individuals (Lim et al., 2017). Furthermore, a recent study exploring risk factors for depression in SCI patients found that self-perceived poor health status and performing less planned exercise were significant risk factors for major depressive disorder (VanDerwerker et al., 2020). The above-mentioned studies also support that the psychological stress of individuals with SCI was significantly improved after the training program, which be attributed to the exercise that provides them the opportunity to build self-confidence. This assumption is also supported by this study, which showed that improved self-efficacy was only observed in adults with SCI in the experimental group.

Physical impairment caused by high-level injury to the spinal cord, especially in those who can only rely on wheelchairs for mobility, may greatly restrict their willingness to exercise (Ellapen et al., 2017). There are a variety of wheelchair exercises for adults with SCI; however, most of these exercises require large or specialized venues and additional equipment expanses, as well as the specific physical function of the body. In fact, the affordability of equipment is also a key barrier to active exercise, especially for those who have to reply to insurance coverage. An exploratory study of exercise barriers in individuals with SCI disclosed that exercise-active participants had a higher household income than non-exercisers (Kehn & Kroll, 2009). Therefore, in the present study, para-table tennis was chosen as an exercise intervention for adults with SCI, because para table tennis offers the benefits of moderate fitness with less space needs for venues, less expensive equipment, and less physical constraints. It also fosters social contact and networking among participants.

In adults with SCI, exercise adherence is an important barrier that needs to be overcome. Decreasing the frequency of exercise to twice or thrice a week may enhance exercise adherence (Gorgey, 2014). In addition, numerous studies have shown that exercising consistently twice a week increases muscle mass, improves metabolic profile, reduces physical pain, and benefits mental health and quality of life in adults with SCI (Astorino & Harness, 2020; Ellapen et al., 2017). Therefore, the frequency of exercise in the present study was designed to be twice a week to prevent a reduction in willingness to exercise and to facilitate exercise adherence.

Although regular exercise is undoubtedly beneficial for cardiovascular and mental health (McNamara et al., 2022; Pinckard et al., 2019), it remains a daunting challenge for adults with SCI. Engagement in physical exercise benefits cardiac autonomic functions (Li & Spitzer, 2020; Nilsson et al., 2020), which in turn improves autonomic nervous system activity and promotes positive mood (Basso & Suzuki, 2017; Speer et al., 2019). Furthermore, the modulation of autonomic balance by para table tennis training observed in this study, is consistent with other studies (Dong, 2016). In contrast, exercise intensity is negatively associated with the reliability of frequency domain measurements (Barrios et al., 2019; Dong, 2016); low-intensity exercise decreases HFnu, but high-intensity exercise increases HFnu. In addition, LFnu and LF/HF have the opposite responses.

Self-efficacy, the confidence that an individual can successfully execute behavior to accomplish desired outcomes, is a key determinant during SCI rehabilitation and is highly correlated with anxiety, depression, frustration, and quality of life (van Diemen et al., 2020). There is increasing evidence that regular exercise habits can confer considerable benefits in terms of self-efficacy as well as ameliorate psychological and physical health (Ersin et al., 2022; Tikac et al., 2022). However, it remains a challenge for patients with SCI who need a wheelchair for mobility. In this study, we found that only four weeks of regular para-table tennis training showed favorable improvements in self-efficacy in adults with SCI. However, self-efficacy is also greatly influenced by feedback and support from coaches and training partners (Collado-Mateo et al., 2021). In other words, the improved self-efficacy of adults with SCI is partly attributable to teamwork and collaborative communication, as well as the sharing of positive emotions or experiences related to exercise or illness.

4.1. Study limitations

This pilot study had several limitations. First, this pilot study adopted purposive sampling to include individuals with SCI who occasionally exercised in the patient support group for SCI. All individuals with SCI expressing interest in participating in this study were included. The lack of power analysis prior to the study was a limitation of this pilot study. Second, the results of this study may not be generalizable to larger populations due to the bias of the participants' willingness to participate in the experimental group and insufficient sample size. Insufficient motivation to engage in regular exercise may cause bias, resulting in the statistical insignificance of some HRV and APG increases. Finally, although this study highlights the need and advantages of regular para-table tennis training, the optimal exercise intensity for adults with SCI remains unclear. Considering the individual differences in exercise habits and health status among patients with SCI, future research should focus on customized exercise intensity and frequency.

5. Conclusion

This pilot study provides insights into the effectiveness of a para table tennis program in improving psychological and cardiovascular health. We found that as little as 4 weeks of regular para-table tennis program in SCI patients can achieve beneficial improvements in their sympathetic output, HRV power, elasticity of the arterial system, vessel state, and other cardiovascular parameters.

Acknowledgments

The authors thank all participants and greatly appreciate the financial support from the Rong Sing Medical Foundation (Grant No. RSMF-1090131) in Taichung, Taiwan.

Author contributions

Study conception and design: Hsi-Kai Tsou, Hsiao-Yu Chen. Data collection: Hsi-Kai Tsou, Hsiao-Yu Chen, Kuan-Chung Shih, and Yueh-Chiang Lin. Data analysis and interpretation: Hsi-Kai Tsou, Hsiao-Yu Chen, and Kuan-Chung Shih. Drafting of the article: Hsi-Kai Tsou, Hsiao-Yu Chen, and Kuan-Chung Shih. Critical revision of the article: Hsi-Kai Tsou and Hsiao-Yu Chen.

Funding

This work was supported by the Rong Sing Medical Foundation, Taichung, Taiwan (Grant No. RSMF-1090131).

Data availability

All data generated or analyzed during this study are included in this article. Further inquiries can be directed to the corresponding authors.

Ethics statement

The study protocol was approved by the Institutional Review Board (IRB) of Taichung Jen-Ai Hospital (JAHIRB-109-70). All participants provided written informed consent before their participation in the study.

Conflict of interest

The authors declare no conflict of interest.

Supplementary material

The supplementary material is available in the electronic version of this article: https://dx.doi.org/10.3233/NRE-240083.

References

Ahn, H., Lee, K., & So, Y. (2021). The Mediating Effect of Disability Acceptance in Individuals with Spinal Cord Injury Participating in Sport for All. *Int J Environ Res Public Health, 18*(20). https://doi.org/10.3390/ijerph182010883

Aitchison, B., Rushton, A. B., Martin, P., Barr, M., Soundy, A., & Heneghan, N. R. (2022). The experiences and perceived health benefits of individuals with a disability participating in sport: A systematic review and narrative synthesis. *Disabil Health J, 15*(1), 101164. https://doi.org/10.1016/j.dhjo.2021.101164

Astorino, T. A., & Harness, E. T. (2020). Improved quality of life and body satisfaction in response to activity-based therapy in adults with spinal cord injury. *Neuroimmunol Neuroinflammation, 7*, 40-50. https://doi.org/10.20517/2347-8659.2019.11

Barrios, L., Oldrati, P., Santini, S., & Lutterotti, A. (2019). *Evaluating the accuracy of heart rate sensors based on photoplethysmography for in-the-wild analysis* Proceedings of the 13th EAI International Conference on Pervasive Computing Technologies for Healthcare.

Basso, J. C., & Suzuki, W. A. (2017). The Effects of Acute Exercise on Mood, Cognition, Neurophysiology, and Neurochemical Pathways: A Review. *Brain Plast, 2*(2), 127-152. https://doi.org/10.3233/BPL-160040

Benarroch, E. E. (2020). Physiology and Pathophysiology of the Autonomic Nervous System. *Continuum (Minneap Minn), 26*(1), 12-24. https://doi.org/10.1212/CON.0000000000000817

Budd, M. A., Gater, D. R., Jr., & Channell, I. (2022). Psychosocial Consequences of Spinal Cord Injury: A Narrative Review. *J Pers Med, 12*(7). https://doi.org/10.3390/jpm12071178

Buker, D. B., Oyarce, C. C., & Plaza, R. S. (2018). Effects of Spinal Cord Injury in Heart Rate Variability After Acute and Chronic Exercise: A Systematic Review. *Top Spinal Cord Inj Rehabil, 24*(2), 167-176. https://doi.org/10.1310/sci17-00028

Chang, M. Y., Chen, H. Y., Cheng, M. L., & Liu, H. Y. (2017). Rebuilding Life: Investigating the Long-Term Homecare Needs of Clients With Spinal Cord Injuries. *J Nurs Res, 25*(4), 276-282. https://doi.org/10.1097/jnr.0000000000000171

Chen, H. Y., Lai, C. H., & Wu, T. J. (2011). A study of factors affecting moving-forward behavior among people with spinal cord injury. *Rehabil Nurs, 36*(3), 91-97, 127. https://doi.org/10.1002/j.2048-7940.2011.tb00072.x

Chen, H. Y., Wu, T. J., Cheng, M. L., & Sung, H. H. (2012). Evaluation of super-link system theory for spinal cord injury patients using participatory action research in a rehabilitation hospital. *Rehabil Nurs, 37*(3), 119-127. https://doi.org/10.1002/rnj.00040

Collado-Mateo, D., Lavin-Perez, A. M., Penacoba, C., Del Coso, J., Leyton-Roman, M., Luque-Casado, A., Gasque, P., Fernandez-Del-Olmo, M. A., & Amado-Alonso, D. (2021). Key Factors Associated with Adherence to Physical Exercise in Patients with Chronic Diseases and Older Adults: An Umbrella Review. *Int J Environ Res Public Health, 18*(4). https://doi.org/10.3390/ijerph18042023

Craig, A., Pozzato, I., Arora, M., Middleton, J., Rodrigues, D., McBain, C., Tran, Y., Davis, G. M., Gopinath, B., Kifley, A., Krassioukov, A., Braithwaite, J., Mitchell, R., Gustin, S. M., Schoffl, J., & Cameron, I. D. (2021). A neuro-cardiac self-regulation therapy to improve autonomic and neural function after SCI: a randomized controlled trial protocol. *BMC Neurol, 21*(1), 329. https://doi.org/10.1186/s12883-021-02355-w

Currie, K. D., Hubli, M., MacDonald, M. J., & Krassioukov, A. V. (2019). Associations between arterial stiffness and blood pressure fluctuations after spinal cord injury. *Spinal Cord, 57*(12), 1057-1063. https://doi.org/10.1038/s41393-019-0316-y

Ding, W., Hu, S., Wang, P., Kang, H., Peng, R., Dong, Y., & Li, F. (2022). Spinal Cord Injury: The Global Incidence, Prevalence, and Disability From the Global Burden of Disease Study 2019. *Spine (Phila Pa 1976), 47*(21), 1532-1540. https://doi.org/10.1097/BRS.0000000000004417

Dolbow, D. R., Gorgey, A. S., Sutor, T. W., Bochkezanian, V., & Musselman, K. (2021). Invasive and Non-Invasive Approaches of Electrical Stimulation to Improve Physical Functioning after Spinal Cord Injury. *J Clin Med, 10*(22). https://doi.org/10.3390/jcm10225356

Dong, J. G. (2016). The role of heart rate variability in sports physiology. *Exp Ther Med, 11*(5), 1531-1536. https://doi.org/10.3892/etm.2016.3104

Ellapen, T. J., Hammill, H. V., Swanepoel, M., & Strydom, G. L. (2017). The health benefits and constraints of exercise therapy for wheelchair users: A clinical commentary. *Afr J Disabil, 6*, 337. https://doi.org/10.4102/ajod.v6i0.337

Ersin, F., Tuluce, D., & Enzin, F. (2022). Examination of exercise benefit/barrier perceptions of individuals with diabetes and affecting factors. *Afr Health Sci, 22*(3), 275-285. https://doi.org/10.4314/ahs.v22i3.29

Gibbons, C. H. (2019). Basics of autonomic nervous system function. *Handb Clin Neurol, 160*, 407-418. https://doi.org/10.1016/B978-0-444-64032-1.00027-8

Gorgey, A. S. (2014). Exercise awareness and barriers after spinal cord injury. *World J Orthop, 5*(3), 158-162. https://doi.org/10.5312/wjo.v5.i3.158

Henke, A. M., Billington, Z. J., & Gater, D. R., Jr. (2022). Autonomic Dysfunction and Management after Spinal Cord Injury: A Narrative Review. *J Pers Med, 12*(7). https://doi.org/10.3390/jpm12071110

Kajaia, T., Maskhulia, L., Chelidze, K., Akhalkatsi, V., & Kakhabrishvili, Z. (2017). The Effects of Non-Functional Overreaching and Overtraining on Autonomic Nervous System Function in Highly Trained Athletes. *Georgian Med News*(264), 97-103. https://www.ncbi.nlm.nih.gov/pubmed/28480859

Kehn, M., & Kroll, T. (2009). Staying physically active after spinal cord injury: a qualitative exploration of barriers and facilitators to exercise participation. *BMC Public Health, 9*, 168. https://doi.org/10.1186/1471-2458-9-168

Laing, S. T., Gluckman, T. J., Weinberg, K. M., Lahiri, M. K., Ng, J., & Goldberger, J. J. (2011). Autonomic effects of exercise-based cardiac rehabilitation. *J Cardiopulm Rehabil Prev, 31*(2), 87-91. https://doi.org/10.1097/HCR.0b013e3181f1fda0

Le, J., & Dorstyn, D. (2016). Anxiety prevalence following spinal cord injury: a meta-analysis. *Spinal Cord, 54*(8), 626. https://doi.org/10.1038/sc.2016.69

Li, H. Q., & Spitzer, N. C. (2020). Exercise enhances motor skill learning by neurotransmitter switching in the adult midbrain. *Nat Commun, 11*(1), 2195. https://doi.org/10.1038/s41467-020-16053-7

Lim, S. W., Shiue, Y. L., Ho, C. H., Yu, S. C., Kao, P. H., Wang, J. J., & Kuo, J. R. (2017). Anxiety and Depression in Patients with Traumatic Spinal Cord Injury: A Nationwide Population-Based Cohort Study. *PLoS One, 12*(1), e0169623. https://doi.org/10.1371/journal.pone.0169623

Malmqvist, L., Biering-Sorensen, T., Bartholdy, K., Krassioukov, A., Welling, K. L., Svendsen, J. H., Kruse, A., Hansen, B., & Biering-Sorensen, F. (2015). Assessment of autonomic function after acute spinal cord injury using heart rate variability analyses. *Spinal Cord, 53*(1), 54-58. https://doi.org/10.1038/sc.2014.195

Manresa-Rocamora, A., Ribeiro, F., Sarabia, J. M., Ibias, J., Oliveira, N. L., Vera-Garcia, F. J., & Moya-Ramon, M. (2021). Exercise-based cardiac rehabilitation and parasympathetic function in patients with coronary artery disease: a systematic review and meta-analysis. *Clin Auton Res, 31*(2), 187-203. https://doi.org/10.1007/s10286-020-00687-0

Martin Ginis, K. A., van der Scheer, J. W., Latimer-Cheung, A. E., Barrow, A., Bourne, C., Carruthers, P., Bernardi, M., Ditor, D. S., Gaudet, S., de Groot, S., Hayes, K. C., Hicks, A. L., Leicht, C. A., Lexell, J., Macaluso, S., Manns, P. J., McBride, C. B., Noonan, V. K., Pomerleau, P., Rimmer, J. H., Shaw, R. B., Smith, B., Smith, K. M., Steeves, J. D., Tussler, D., West, C. R., Wolfe, D. L., & Goosey-Tolfrey, V. L. (2018). Evidence-based scientific exercise guidelines for adults with spinal cord injury: an update and a new guideline. *Spinal Cord, 56*(4), 308-321. https://doi.org/10.1038/s41393-017-0017-3

McNamara, G., Robertson, C., Hartmann, T., & Rossiter, R. (2022). Effectiveness and Benefits of Exercise on Older People Living With Mental Illness' Physical and Psychological Outcomes in Regional Australia: A Mixed-Methods Study. *J Aging Phys Act*, 1-13. https://doi.org/10.1123/japa.2021-0514

Migliorini, C., Tonge, B., & Taleporos, G. (2008). Spinal cord injury and mental health. *Aust N Z J Psychiatry, 42*(4), 309-314. https://doi.org/10.1080/00048670801886080

Nilsson, J., Ekblom, O., Ekblom, M., Lebedev, A., Tarassova, O., Moberg, M., & Lovden, M. (2020). Acute increases in brain-derived neurotrophic factor in plasma following physical exercise relates to subsequent learning in older adults. *Sci Rep, 10*(1), 4395. https://doi.org/10.1038/s41598-020-60124-0

Pinckard, K., Baskin, K. K., & Stanford, K. I. (2019). Effects of Exercise to Improve Cardiovascular Health. *Front Cardiovasc Med*, *6*, 69. https://doi.org/10.3389/fcvm.2019.00069

Schönenberg, M., Reimitz, M., Jusyte, A., Maier, D., Badke, A., & Hautzinger, M. (2014). Depression, posttraumatic stress, and risk factors following spinal cord injury. *Int J Behav Med, 21*(1), 169-176. https://doi.org/10.1007/s12529-012-9284-8

Serra-Añó, P., Montesinos, L. L., Morales, J., López-Bueno, L., Gomis, M., García-Massó, X., & González, L. M. (2015). Heart rate variability in individuals with thoracic spinal cord injury. *Spinal Cord*, *53*(1), 59-63. https://doi.org/10.1038/sc.2014.207

Serra-Ano, P., Montesinos, L. L., Morales, J., Lopez-Bueno, L., Gomis, M., Garcia-Masso, X., & Gonzalez, L. M. (2015). Heart rate variability in individuals with thoracic spinal cord injury. *Spinal Cord*, *53*(1), 59-63. https://doi.org/10.1038/sc.2014.207

Speer, K. E., Naumovski, N., Semple, S., & McKune, A. J. (2019). Lifestyle Modification for Enhancing Autonomic Cardiac Regulation in Children: The Role of Exercise. *Children (Basel)*, *6*(11). https://doi.org/10.3390/children6110127

Tikac, G., Unal, A., & Altug, F. (2022). Regular exercise improves the levels of self-efficacy, self-esteem and body awareness of young adults. *J Sports Med Phys Fitness, 62*(1), 157-161. https://doi.org/10.23736/S0022-4707.21.12143-7

Tsou, H. K., Shih, K. C., Lin, Y. C., Li, Y. M., & Chen, H. Y. (2022). Altered heart rate variability and pulse-wave velocity after spinal cord injury. *World J Clin Cases*, *10*(27), 9680-9692. https://doi.org/10.12998/wjcc.v10.i27.9680

van Diemen, T., Craig, A., van Nes, I. J. W., Group, S.-S., Stolwijk-Swuste, J. M., Geertzen, J. H. B., Middleton, J., & Post, M. W. M. (2020). Enhancing our conceptual understanding of state and trait self-efficacy by correlational analysis of four self-efficacy scales in people with spinal cord injury. *BMC Psychol, 8*(1), 108. https://doi.org/10.1186/s40359-020-00474-6

VanDerwerker, C. J., Cao, Y., Gregory, C. M., & Krause, J. S. (2020). Associations Between Doing Planned Exercise and Probable Major Depressive Disorder in Individuals Following Spinal Cord Injury. *Top Spinal Cord Inj Rehabil, 26*(1), 11-20. https://doi.org/10.1310/sci2601-11