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Acute effect of HAL (limb type)-assisted cybernic voluntary control squat exercise on tennis serve speed

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ABSTRACT

The fastest serve at the 2022 US Open Tennis was 141 mph (226.9 km/h, Alexander Bublik, KAZ) and 128 mph (205.9 km/h, Coco Gauff, USA) for men and women, respectively. This speed is expected to increase in the future. Most studies focused on improving serve performance have been conducted in the fields of sports biomechanics and exercise physiology. There are no studies focusing on the voluntary control of the brain, spinal cord, motor nerves, musculoskeletal system, and service performance. Recently, a wearable cyborg, Hybrid Assistive Limb (HAL), has been utilized as a rehabilitation device in patients with stroke, cerebral palsy, and spinal cord injury. We aimed to determine the acute effect of Cybernic Voluntary Control squat exercises using HAL on the serve speed. Four male tennis coaches with extensive teaching experience (mean age: 32.5 ± 0.6 years, teaching experience: 10.5 ± 0.6 years) were included in the study. The results showed an increase of approximately 7% in the in serve speed after HAL-assisted squatting. This was attributed to the interactive biofeedback between HAL and the participants, which may have produced the immediate effect. HAL use could maximize the physical functions of tennis players and guide post-injury rehabilitation exercises.

Key words: Motor learning, rehabilitation, interactive bio-feedback.

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INTRODUCTION

The fastest serve at the 2022 US Open Tennis was 141 mph (226.9 km/h; Alexander Bublik, KAZ) and 128 mph (205.9 km/h; Coco Gauff, USA) among the men and women, respectively. This speed is expected to continue increasing in the future (Tables 1 and 2) (USTA, 2022).

Until now, most studies on improving serving performance has come from the fields of sports biomechanics and exercise physiology. No study has focused on the voluntary brain → spinal cord → motor nerve → musculoskeletal system pathway in the field of neuroscience. Recently, the Hybrid Assistive Limb (HAL) (Kawamoto et al., 2010), a wearable cyborg developed by Sankai et al. (2014), has been utilized and is effective as a rehabilitation device in patients with stroke, cerebral palsy, and spinal cord injury (Nakajima, 2011). Yasunaga et al. (2022) evaluated the immediate changes in low back pain and hip flexibility and adverse events after biofeedback physical therapy using HAL; they reported significant positive changes. However, the potential use of HAL in sports remains unknown. Furthermore, it is necessary to verify its usefulness in improving performance and guiding exercises. We aimed to determine the effect of Cybernic Voluntary Control (CVC) squat exercises using HAL on the serving speed.

Table 1

2022 US Open Tennis rankings of the fastest serves among men (USTA, 2022).

Fastest serves in US Open 2022 I MEN			
Rank	Matches	Player	Fastest Serve Speed
1	2	A. Bublik	141 mph
2	3	T.Paul	139 mph
2	1	B. Shelton	139 mph
4	2	B. Van de Zandschulp	138 mph
4	5	F. Tiafoe	138 mph
4	1	J . Sock	138 mph
4	5	M. Berrettini	138 mph
8	5	N. Kyrgios	136 mph
8	2	G. Dimitrov	136 mph
8	1	F. Verdasco	136 mph
8	1	J. Munar	136 mph
8	2	J. Thompson	136 mph
8	3	J . Draper	136 mph
8	2	A. Popyrin	136 mph

Table 2

2022 US Open Tennis rankings of fastest serves among women (USTA, 2022).

Fastest serves in US Open 2022 I WOMEN			
Rank	Matches	Player	Fastest Serve Speed
1	5	C. Gauff	128 mph
2	4	L. Samsonova	123 mph
3	2	B. Haddad Maia	120 mph
3	3	P. Martic	120 mph
5	3	S. Williams	119 mph
5	3	X. Wang	119 mph
7	3	M. Keys	118 mph
7	1	V. Williams	118 mph
7	5	C. Garcia	118 mph
7	1	0. Dodin	118 mph

METHODS AND PROCEDURES

Subjects

Four experienced tennis coaches (mean age: 32.5 ± 0.6 years), with a teaching experience of 10.5 ± 0.6 years, were included in the study. The physical characteristics and teaching history of the participants are shown in Table 3. These coaches were selected for the study because the learning curve of their serve skills had already plateaued.

Procedure

Before the experiment, a semi-structured interview was conducted to obtain the coaching history (e.g., injuries). Subsequently, a sufficient warm-up time was allowed prior to conducting the experiment. The serve speeds and hitting points were measured using a HEAD Tennis Sensor (U.S.A.) attached to a special racket. Keaney & Reid (2018) confirmed that the stroke volume and intensity captured by HEAD Tennis Sensors are as reliable and valid as those captured by motion capture systems. The DUNLOP Fort tennis ball was used (DUNLOP). The participants were asked to hit 10 flat serves as hard as possible to a target set up in front of them. After each experiment was completed, a sufficient rest period was allowed to avoid the learning curve being affected.

Table 3

Physical characteristics and teaching history of the participants.

	Age (years)	Height (cm)	Body Weight (kg)	BMI	Teaching experience (years)
Subject A	32	165	64.4	23.5	10
Subject B	32	173	70.2	23.4	10
Subject C	33	179	73.5	22.8	11
Subject D	33	176	75	24.2	11
Mean ±SDs	32.5 ± 0.6	173.25 ± 6.0	70.8 ± 4.7	23.5 ± 0.6	10.5 ± 0.6

Figure 1. *Tennis racket-mounted motion analysis sensor (HEAD Tennis Sensor; ZEPP).*

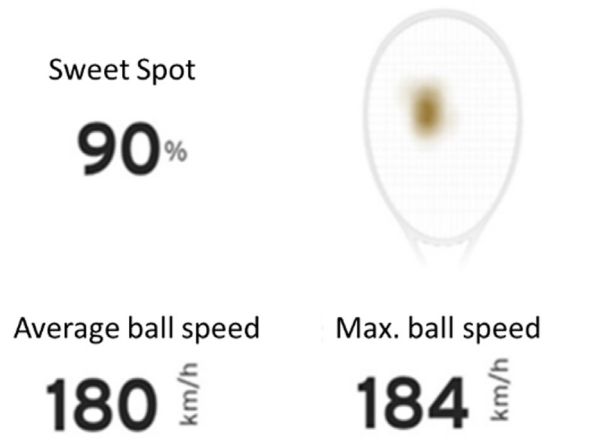

Figure 2. *Average and maximum ball speeds and hitting points as calculated using HEAD Tennis Sensor.*

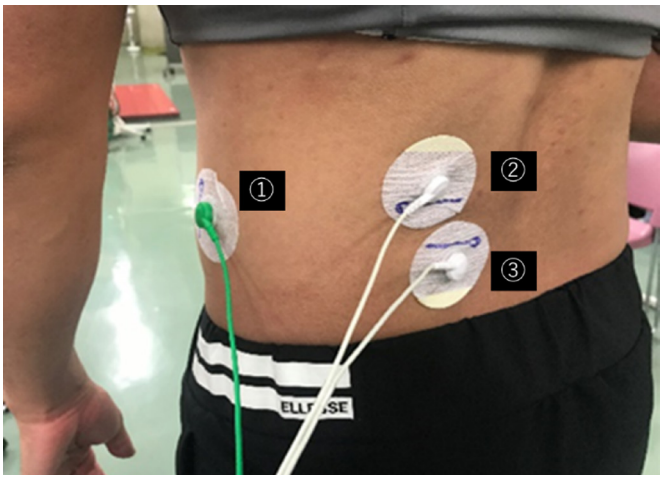

Figure 4. *Electrode positions over the back. 1: Grounding. 2 & 3: Erector spinae muscle.*

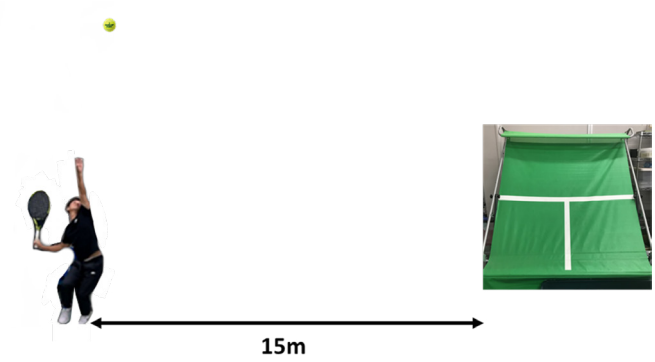

Figure 3. *Experimental setup.*

Figure 5. *CVC squat exercise with the Hybrid Assistive Limb®.*

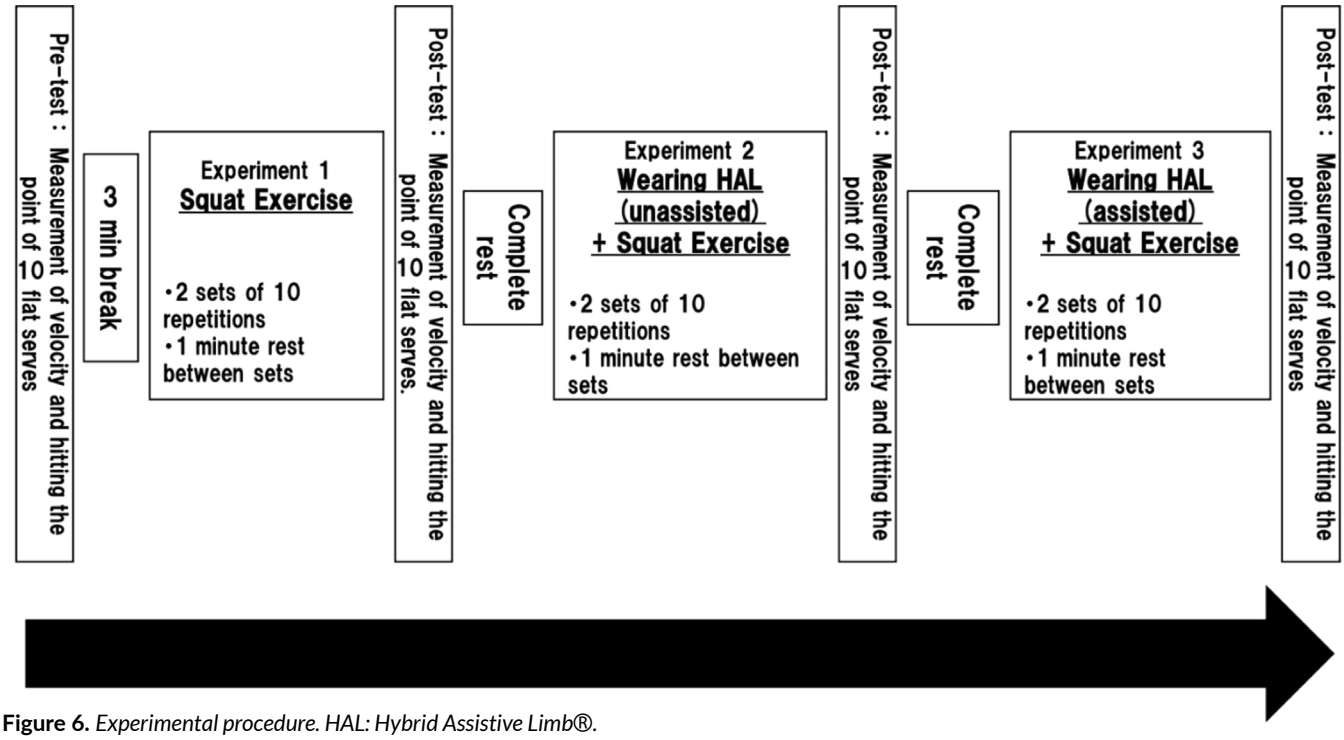

Figure 6. *Experimental procedure. HAL: Hybrid Assistive Limb®.*

Statistical analysis

Serve speeds following (1) squat, (2) squat wearing HAL, and (3) squat wearing HAL in the CVC mode were compared to the pre-experimental serve speed (two-group comparisons). Wilcoxon's signed-rank test was used for the comparison. SPSS (version 28.0; IBM Japan, Tokyo, Japan) was used for all statistical analyses. Statistical significance was set at $p<0.05$.

Ethical considerations

This study was approved by the Ethics Review Committee of Meiji University (No. 557). The participants were provided with written and verbal information regarding the purpose and content of the study. It was explained that the results would not be used for anything other than for this study and that participation was voluntary. In addition, it was explained that there would be no disadvantage to not participating in this study. Finally, the participants could leave during the study.

RESULTS AND DISCUSSION

The average serve speed of the four participants was 166.9 ± 12.3 km/h, 170.1 ± 12.4 km/h, 171.9 ± 11.6 km/h, and 179.1 ± 7.0 km/h in the pre-test, squatting under body weight, squatting without HAL assistance, and squatting with HAL assistance (CVC mode) conditions, respectively. The speed increased significantly in all test conditions compared to the pre-test values (Experiment 1: $p=0.003$, Experiment 2: $p<0.001$, Experiment 3: $p<0.001$).

There was a 2%, 3%, and 7% increase in speed in the squatting under body weight, squatting without HAL assistance, and squatting with HAL assistance (CVC mode) conditions, respectively (Figure 7).

Kovacs & Ellenbecker (2011a) classified serves into eight phases from start to completion: (A) initiation, (B) release, (C) loading, (D) cocking, (E) acceleration, (F) impact, (G) deceleration, and (H) completion. The loading phase is important because the lower limb drive generates a large ground reaction force. The importance of leg drive in efficiently transferring lower limb power to increase the serve velocity has been tested using various methods, including lower limb stance techniques. Their disadvantages and advantages have also been reported by several coaches and researchers (Bahamonde & Knudson, 2001; Elliott & Wood, 1983; Martin et al. 2012). Serve speed is related to the amount of muscular force exerted by a powerful leg drive during the loading phase (Bahamonde, 1997). In addition, elite players exert greater horizontal force and use the body's pushing motion to create a series of backward-to-forward movements to hit a fast serve (Girard et al., 2005). Squats and front and side lunges using the body weight are effective exercises, and exercises performed on an unstable balance board improve serve performance (Kovacs & Ellenbecker, 2011b).

HAL can detect weak "bioelectric potential signals" generated from an individual's body surface using sensors and can assist in muscle activity. The driving torque generated by the biopotential signals of the wearer's erector spinae muscles gets transmitted to the trunk and lower limbs via both fixed belts (Abe et al., 2018). Subsequently, the brain and nervous system (brain → spinal cord → motor nerves → musculoskeletal system → HAL → musculoskeletal system → motor nerves → spinal cord → brain) and interactive bio-feedback between the brain/nervous system, body, and HAL (brain → spinal cord → motor nerves → musculoskeletal system → HAL → musculoskeletal system → motor nerves → spinal cord → brain) strengthen and adjust the interconnections and improve its function (Grüneberg et al., 2018; Nakajima et al., 2021; Sankai, 2014; Sankai & Sakurai, 2018).

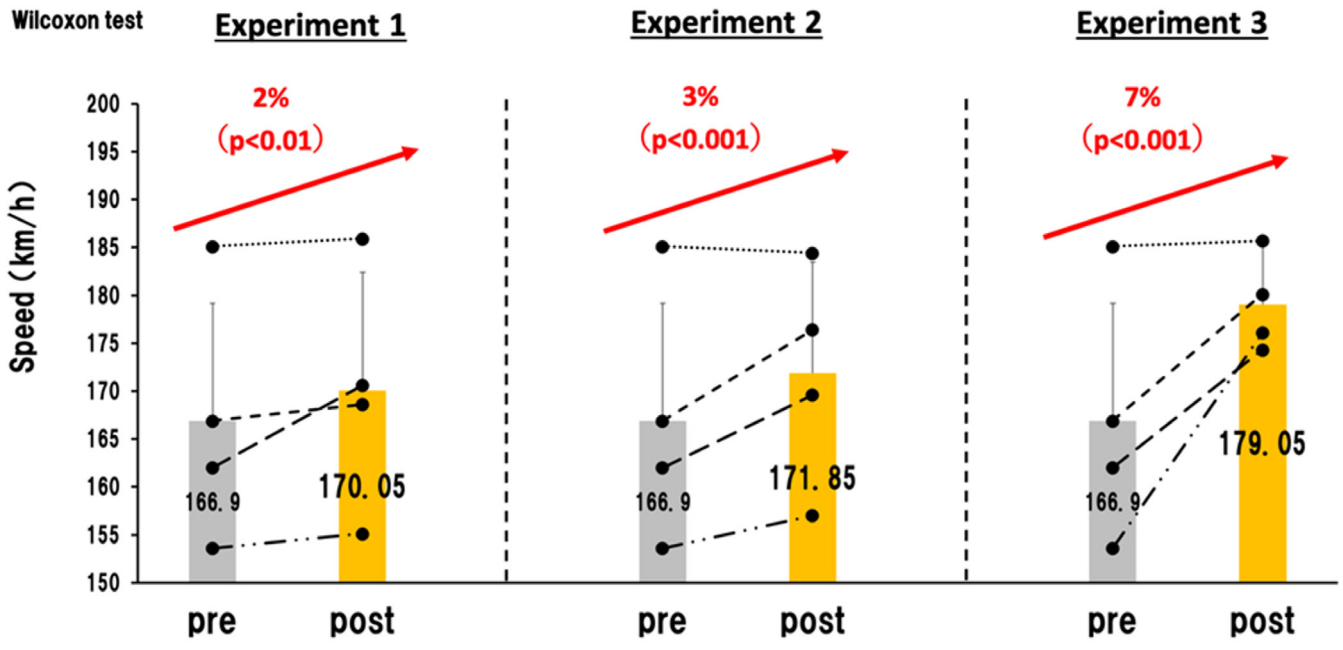

Figure 7. *Change in serve speed from pre-test to post-test condition.*

Squatting using HAL is a CVC exercise that provides voluntary assistance based on bioelectrical signals, which is an evolution from the commonly practiced body weight-based squatting. HAL-assisted squatting stimulates and mobilizes the lower limb muscles and nerves that have not been used up to this point, establishing efficient interactive biofeedback learning and possibly increasing the serve speed.

Limitations and future research

Because this study used a special experimental apparatus (HAL), only four participants were included in the study. Future studies with a larger sample size and other methods, such as group set-ups for measurement, will be required. In addition, "leg drive," which is thought to be a major factor in increasing the serve speed, was not analyzed in this experiment using force plates and a three-dimensional motion analysis device. We would like to perform further studies considering these factors.

CONCLUSION

This study aimed to determine the effects of HAL-assisted CVC squat exercises on the serve velocity. We found a 2%, 3%, 7% increase in speed in the body weight-based squatting, squatting without HAL-assistance, and squatting with HAL-assistance (CVC mode) conditions, respectively. The use of HAL could help tennis players recognize and utilize their latent physical abilities and motor functions. Additionally, it could maximize their physical functions and provide guidance during post-injury rehabilitation.

CONFLICT OF INTEREST AND FUNDING

The authors declare that they do not have any conflict of interest and that they did not receive any funding to conduct the research.

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