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THE ACUTE EFFECTS OF A GRIP-CONSTRAINT TOOL ON UPPER BODY AND RACKET KINEMATICS DURING TENNIS FOREHANDS

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The purpose of this study was to compare the acute effect of a grip-constraint tool on upper body and racket kinematics during tennis single-handed forehand strokes. Upper-body and racket kinematics for two grip conditions, Preferred (self-selected) and Grip-constraint tool (fixed semi-western forehand grip) were captured for eleven tennis players using a 22-camera Vicon motion capture system (240 Hz). Using a grip-constraint tool resulted in a more closed racket face tilt (~4°) at ball impact while having variations in joint rotations across the shoulder, elbow and wrist. This possibly demonstrates the participant's ability to self-organise compensatory angular rotations across the upper limb to achieve similar impact orientations. Collectively, these data demonstrate the acute responses to modifying grip technique using a grip-constraint tool during single-handed down-the-line forehands.

KEYWORDS: Grip-constraining tool, kinematics, grip, tennis, self-organisation.

INTRODUCTION: Grip positions are fundamental and essential components of effective tennis shot performance (Elliott, 2006). Previous research has primarily focused on injury and performance attributes of grip positions across multiple strokes (Busuttil et al., 2020, 2022; Elliott & Christmass 1994; Elliott, Takahashi, & 1997; Stuelcken et al., 2017, Tagliafico et al., 2009), however, limited research has explored the development of grip positions. Traditionally, coaches use many methods when developing this skill, with one common practice being the use of physically-constraining tools (PCTs). PCTs are devices that guide an athlete's movement and have been shown to improve shot accuracy during the golf drive (Yost, Strauss, and Davis, 1976). In tennis, up to 65% of coaches would welcome the use of PCTs for grip position development (Busuttil et al., 2021) as PCTs might provide a fixed reference point for athletes whilst simultaneously constraining their movement to the desired path. Given the fundamental contribution of grip positions to tennis performance and the limited research on the effects of PCTs on shot kinematics, a detailed biomechanical understanding of the effect of PCTs on upper limb kinematics during single-handed forehands is warranted. The aim of this exploratory study was to compare the acute effect of a grip-constraint tool on upper-body kinematics of tennis athletes during a single-handed forehand. It was hypothesised that using a grip position PCT would result in lower acute shot accuracy and reduced racket head velocity compared with preferred grip variations.

METHODS: A convenience sample of eleven right-handed tennis players considered either tier two or tier three athletes under the participant classification framework (McKay et al., 2022) agreed to participate in the study (#HEC21082). All testing was completed on a standard sized singles tennis court constructed inside a biomechanics laboratory (La Trobe University, Melbourne, Australia) using modular flooring tiles (MSF Sports, MSF PRO Tile, Melbourne Australia) and a portable tennis net (Figure 1a). All participants used their personal racket during testing to account for individual preferences and minimise environmental influences on swing performance and mechanics. Using their preferred grip position, participants were required to perform successive single-handed, topspin forehand attempts into a deep, down-the-line target zone (3 m^2; Figure 1a). Once the successful forehands were completed, the participants repeated the protocol using the PCT (GripFixer™, Copenhagen, Denmark) attached to their grip handle, constraining the participants to a semi-western grip position

(Figure 1b and c). Grip conditions (Preferred and Grip-constraint) were counterbalanced during data collection. The participants received inbound balls (15 m/s) via a Slinger Bag ball launcher (Slinger® Inc, Windsor Mill, United States), directed from the centre of the tennis court on the opposite side of the net. Marker trajectories were captured using a 22-camera Vicon Vantage motion capture system (Vicon Motion Systems Ltd., Oxford, UK; 240 Hz). Fifty-four reflective markers (12.5 mm in diameter) were attached to the shoulders and upper limbs of each participant, using rigid clusters and single markers (Wells et al., 2018; Whiteside et al., 2015). An additional six light rubber semicircular markers (8 mm in diameter) were placed on each participant's racket. Individual marker coordinates were reconstructed with Nexus software (Vicon Motion Systems Ltd., Oxford, UK, V 2.14.0) where marker trajectories were filled using spline or rigid 'gap filling' functions. Marker trajectories were then filtered using a low-pass Butterworth filter (15 Hz). A nine-segment linked upper limb kinematic model was applied to the data with the racket modelled as an additional segment (Wells et al., 2018, Whiteside et al., 2015). Kinematic variables of interest were separation angle, and shoulder, elbow, and wrist joint angles at ball impact. Joint movements in internal rotation (shoulder), pronation (elbow), flexion (elbow and wrist) and ulnar deviation (wrist) were defined as positive. A positive separation angle is represented by rotation in the anti-clockwise direction from parallel shoulder and hip alignment (Landlinger et al., 2010). Shot accuracy (%) and peak racket head linear velocities (m/s) during the swing (measured prior to impact) were used as performance outcomes. Joint angles were expressed using the standard Euler Z-X-Y convention (Wu et al., 2005). A neutral (0°) racket face tilt angle was recorded when the racket face was vertically aligned and parallel to the net. A negative racket face tilt was considered as a "closed" racket face, directed anteriorly to the ground. All kinematic variable data are reported at the instance of ball-racket impact. A total of six trials per participant were used for analysis using Jamovi (v 2.3.12, Jamovi project). A paired samples t-test was used to assess the significant differences between grip conditions (Preferred vs Grip-constraint). An alpha level of .05 was used for all statistical analyses. Cohen's d_z effect sizes were also calculated and defined as small (d_z = .20–.49), medium (d_z = .50–.79) and large (d_z = > .80; Cohen, 1988).

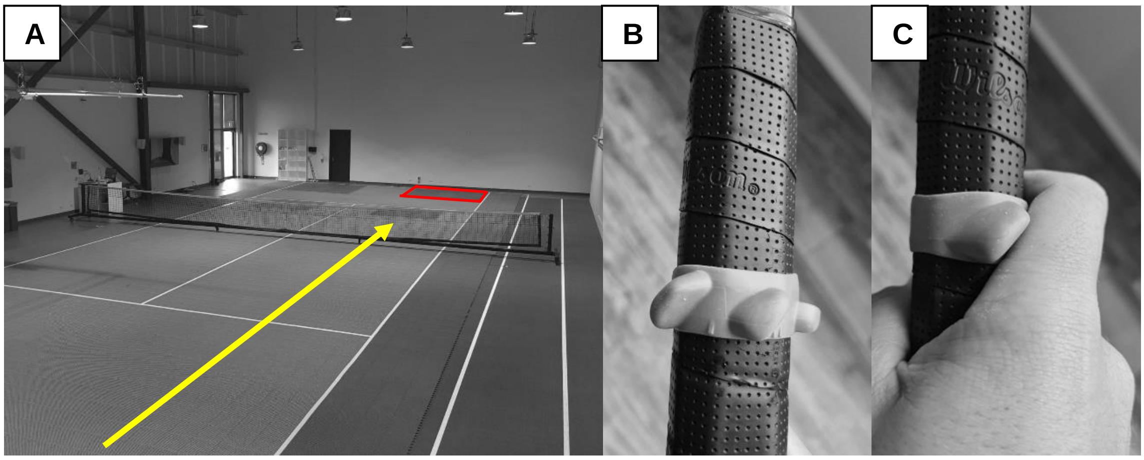

Figure 1. **A) Testing court with a yellow arrow depicting the hitting direction and red box depicting the target zone. B) Grip-constraint tool being applied to a user's racket handle. C) Index finger being physically constrained in one of the grooves on the Grip-constraint tool.**

RESULTS: There was a significant difference in racket face tilt (p = .005, d_z = 1.07), in which the Grip-constrained condition ([mean ± SD]; -3.2 ± 2.8°) resulted in a slightly more closed racket face compared with the Preferred grip condition (0.6 ± 2.6°) at ball impact. Despite not being statistically significant, using the Grip-constraint tool resulted in decreased shot accuracy by 10% when compared with the Preferred condition. There were no other significant differences observed for any performance or kinematic variable between the Preferred and Grip-constrained condition at the ball-racket impact for down the line forehands with most variables reported with a small effect size (p > .05, d_z;< .50 Table 1).

DISCUSSION: This exploratory study investigated upper-limb kinematic differences between Preferred and Grip-constrained grips during single-handed down-the-line forehands in skilled tennis players. At ball impact, there was limited evidence of angular positional changes in the upper body and racket between the grip conditions. The use of a grip-constraint tool could be classed as an unfamiliar skill for participants. Unfamiliar skills are performed with more rigidity than familiar skills (Bernstein, 1967). Typically, athletes would use a grip-constraint tool for an extended period of time, affording them the opportunity to explore movement solutions and

***Table 1*. Shot accuracy, racket, and upper body kinematics measured at impact (mean ± SD).**

	Preferred		**GripFixer**		**Effect size (*d_z*)**	
Performance variables						
Accuracy (%)	50.8 ± 14.2		41.2 ± 11.0		.45	
Peak horizontal racket linear velocity (m/s)	26.3 ± 1.5		26.0 ± 1.8		.13	
Peak vertical racket linear velocity (m/s)	17.2 ± 4.5		18.1 ± 4.5		-.33	
Racket face tilt (°) *****	0.6 ± 2.6		-3.2 ± 2.8		1.07	
***Upper body Kinematics* (°)**						
Separation angle	15 ± 11		11 ± 9		-.39	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**
Shoulder						
Flexion/Extension	-25 ± 23	38 ± 22	-23 ± 24	39 ± 23	-.16	-.09
Abduction/Adduction	-23 ± 9	-34 ± 10	-24 ± 5	-32 ± 10	.22	-.13
Internal/External rotation	-28 ± 20	-7 ± 17	-26 ± 21	-6 ± 17	-.18	-.06
Elbow						
Flexion/Extension	99 ± 20	56 ± 20	101 ± 24	70 ± 25	-.19	-.45
Supination/Pronation	97 ± 20	120 ± 10	87 ± 29	92 ± 58	.44	-.46
Wrist						
Flexion/Extension	-30 ± 14	-56 ± 9	-30 ± 13	-44 ± 32	-.10	-.37
Ulnar/Radial deviation	-5 ± 9	22 ± 7	-5 ± 9	20 ± 14	-.23	.19

‘ * ’ indicates a significant difference between Preferred and Grip-constrained conditions.

self-organise to the most optimal technique to improve shot accuracy. Similar angular kinematics have been reported at the dominant elbow and wrist in elite and high-performing tennis athletes (Landlinger et al., 2010). The Preferred condition racket-arm elbow flexion at ball impact in the current study was similar to that reported by Landlinger and colleagues (2010) for elite (59 ± 13°) and high performance (60 ± 15°) athletes. Although not statistically different to the Preferred condition, the participants executed forehands in the Grip-constrained condition with 14° less racket-arm elbow flexion, which was a small effect size. A similar trend can be observed at the racket-arm wrist with participants performing the forehand in the Preferred condition with similar wrist extension to that used by elite (54 ± 10°) and high performance (52 ± 5°) players as reported in previous research (Landlinger et al., 2010). However, the participants in the current study had 12° less wrist extension in the Grip-constrained condition. These outcomes suggest that using a Grip-constraint tool, which perturbs familiar grip position, possibly limits the degrees of freedom (or movement options) available to achieve end point orientations at ball-racket impacts. The magnitude of difference between conditions may be considered small (4°) despite a large effect size being reported. This data might suggest that joint excursion is restricted at the shoulder, elbow and wrist. As a result of restricted joint excursion, there is likely coordination coupling between shoulder abduction/adduction, and elbow and wrist flexion/extension to achieve effective ball-racket impact orientations. Previous research has reported that altering non-dominant grip position technique results in delayed dominant arm peak adduction angular velocity during double-handed backhands (Busuttil et al., 2022), while maintaining shot accuracy. Although not reported in the current study, it is possible that there were differences in temporal kinematics for down-the-line forehands when grip is modified, emphasising the participant's ability to self-organise movement solutions for successful outcomes. A possible limitation of the current study is participants' acute use of the Grip-constraint tool during a single session, having a small habituation period of 10 machine projected balls. Therefore, the results of this study should not be extrapolated to the long-term effect of using Grip-constraint tools. Future work should consider the acute temporal kinematics of using PCTs for tennis shot performance and assess the longitudinal effects of PCTs for skill development in tennis.

CONCLUSION: This study demonstrated that acute use of a grip-constraint tool results in similar shot performance and upper-body kinematics in skilled tennis athletes. Racket face tilt was significantly more closed in the Grip-constraint condition. This possibly demonstrates participants' ability to self-organise compensatory angular rotations in the upper limb to achieve similar impact orientations, manifested from a reduced joint excursion at the shoulder, elbow and wrist. These data introduce a novel understanding of the acute effects of using a grip-constraint tool for a specific grip position, and builds a foundation for future work with PCTs for skill development in tennis. Future work should explore the longitudinal effects of PCTs for grip-specific skill development in tennis.

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