Original Article

Effect of Tennis Racket Damper on the Peak Force and Damping Time

Mason Porramatikul MD[1], Thiti Meeopartmongkon MD1

[1] Department of Orthopedics, Faculty of Medicine, Vajira Hospital, Navamindradhiraj University, Bangkok Thailand

Objective: To study the effect of two damper shapes on tennis racket on the peak force and damping time at the grip area for a centre or off-axis locations of the ball-impact.

Materials and Methods: The peak force and damping time were tested on tennis rackets grips with 3 different settings: use of damper: no damper, button damper, or worm damper. Tennis balls were served using a tennis strike-simulating machine using 30 m/s racket speed. The peak force and damping time were recorded from a force transducer attached to the grip and were compared when the ball-strokes were at four locations: centre, above centre, below centre, and off-axis.

Results: Both types of dampers did not reduce the impact force at the grip regardless of the location. However, the worm damper yielded a 15% decrease in damping time of an off-axis impact: 230.2±3.1 ms to 196.1±13.8 ms ($p = 0.002$). Neither damper reduced the damping time with the on-axis impacts.

Conclusion: Worm damper reduced the racket's damping time when the ball impacts in an off-axis position but does not affect the impact force transmitted to the other locations of the grip.

Keywords: Damping time, Peak force, Impact locations, Damper, Vibration

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Playing tennis can cause musculoskeletal injury. The force of repeated impacts between the ball and string bed is transferred to the tennis player through the racket, which can lead to repetitive stress injuries(1-3). The tennis serving is the most complex movement in a competitive game which can cause injury to the upper limbs(4).

Studies have shown that racket structural properties, racket velocity, string tension, grip force, stroke form, tennis ball elasticity, and ball impact location can influence the force transmitted to the player's hands(1,5-9). Damper is often installed to reduce the force that passes from a tennis racket to the player's hands and arms when a tennis ball impacts the racket's string bed. The dampers can certainly reduce the impact force and vibration of the racket. However, very few studies have focused on the effectiveness of such dampers(10-14).

Dampers are commonly divided into two groups: button-shape and worm dampers. The button-shape dampers are attached to two vertical strings and one horizontal string whereas the worm dampers are long and thin and are attached to multiple vertical strings.

Mohr et al found that a damper reduced the vibration at the forearm and the noise produced when the ball was hit(11). Other studies did not have such findings(12). Stroede found that a damper could not reduce the vibration of the frame when hitting a ball because the damper mass (5 to 10 g) is much lesser than the mass of the tennis racket (>200 g)(12). Therefore, it cannot absorb the vibrations originating in the racket. Li et al also found that the damper did not reduce vibration even if the ball impacted at a dead spot (high vibration amplitude) or at a node (low vibration amplitude)(10).

Ameer et al stated that dampers reduce the myoelectric activity of the wrist extensor muscle only

Correspondence to:
Porramatikul M. Department of Orthopedics, Faculty of Medicine, Vajira Hospital, Navamindradhiraj University, Bangkok 10300, Thailand.
Phone: +66-81-8328007
E-mail: masonortho@yahoo.com, mason@nmu.ac.th

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in a less experienced tennis player, but not in experienced tennis players(15). Timme et al constructed a variety of models for the vibration of the string bed. Their results suggested that dampers could reduce some high frequency vibrations (>800 Hz) in tennis rackets. However, these simulations dealt with acoustic vibrations and not realistic tennis ball impacts that generally strike a single position on the string bed(13). The ball impact location affects the force that is passed through the tennis racket(16-19). Li found that hitting a ball at the dead spot results in an impact force that was approximately 1.6 times higher compared with that generated after hitting a ball at a node spot(17). Henning found that if a tennis ball impacts 12 cm above the centre of percussion, the vibration at the wrist was more than three times greater than when the impact is at the centre of percussion(6). Henning's study fired a ball at a fixed racket. In practice, however, players hold the racket; therefore, the pressure applied on the grip would not evenly been distributed. The position of the impact point was also not well confirmed in these experiments. Both factors affect the impact force transferred to the wrist.

Furthermore, previous studies only tested damper effects at 10 to 20 m/s racket speeds(6,9,10,20,21), which were slower than an actual serve of a professional tennis player's serve which was approximately 30 m/s(8).

Objective

The present study was to investigate the effects of the two damper shapes, button and worm dampers, on the peak force and damping time measured at the grip and four different locations of ball impact.

Materials and Methods

This experimental study was approved by the Ethics Committee of the institution. Service flat serves strokes were simulated by a tennis strike simulating machine [TESMA] that can move the tennis racket at speeds approaching those of professional serves(22,23) at the Testing and Research Centre for Sports Materials and Equipment, Faculty of Sports Science, Chulalongkorn University, Bangkok, Thailand (Figure. 1). Factors that can affect the transfer of the force to the grip were controlled along with the location of ball impacts(6,7,9,12,14,16,17,19,21,24-26).

A Yonex (Ezone Xi 100, Tokyo, Japan) tennis racket was strung at 50±1 lb. tension. The racket handle was clamped to the TESMA rotating swing arm with a counter-weight on the shaft of a striker driven by a 5-HP servo motor. The servo motor adjusted the speed of the racket with precise control of its rotating speed. The default speed is 450 rpm, which was similar to the speed of a tennis pro's pre-impact racket velocity (30 m/s) according to Chow et al(8).

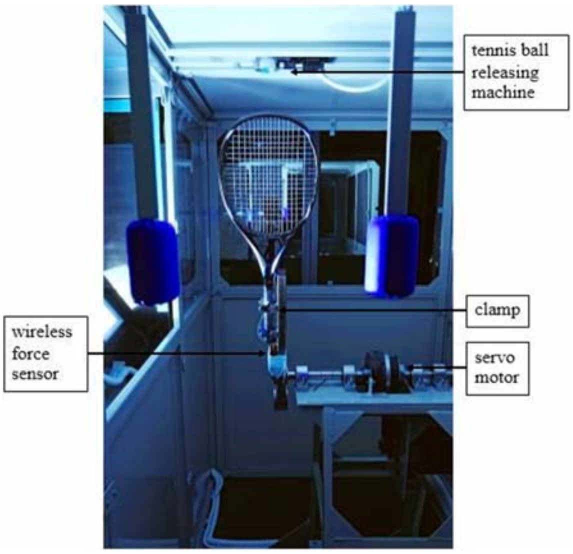

Figure 1. The Tennis Strike Simulating Machine Consists of a Striker Driven by 5 HP Servo-Motor and 3D Motion Capture and Analysis System with 2,000-Hz High Speed Camera. Experimental data were captured and recorded from Flexiforce WELF2 system with WB201-H sensor attached to the racket's handle.

The racket grip was connected to a wireless force transducer (Flexiforce WELF2 system with WB201-H sensor). The wireless force transducer is a piezoelectric sensor that converts force into an electrical signal and is used to measure impact force. These measurements are presented in a force graph and spreadsheet after they are wirelessly transmitted to a workstation. A high-speed DMAS 2,000 Hz DVRs camera was positioned behind the racket to confirm the ball impact location. Calibration frame of 0.5x0.5x0.5 m with 15 markers was used to calibrate the system for high speed, high precision, and high accuracy with an estimated error of 0.043%.

Dunlop FORT all-court tennis balls were tested for their adherence to criteria according to the International Tennis Federation [ITF] specifications. Each tennis ball was not used for more than 30 impact strikes to ensure consistency of the bouncing properties in all experimental trials. In the control group, the racket had no damper installed.

Four impact locations were tested. Point 1 was the geometric centre of the string bed (CN). Point 2 was 6 cm above the CN (AC). Point 3 was 6 cm below the CN (BC). Point 4 was 6 cm to the right of the CN (off-axis, OA) (Figure 2). Peak force and damping time were recorded via Flexiforce WELF2 software. Peak force is the highest force measured at the grip, measured in N (point B in Figure 2). The damping time is the period over which the grip vibrates from the moment of impact until vibration ceases. Each trial was repeated three times.

The first group of trials tested rackets without any dampers. The second group of trials tested rackets fitted with a button damper (custom damp, Babolat, Lyon, France). The button damper was attached to two middle vertical strings and the horizontal string nearest to the grip (the first horizontal string) (Figure 3a). The other conditions were identical to those of the control trials. The third group of trials tested a worm damper (Shockbuster II, Gamma Sports, Pittsburgh, PA, USA) which was attached along ten vertical strings in the middle of the racket, just below the first horizontal string (Figure 3b). The string tension was checked after every 10 trials to ensure consistency.

Statistical analysis

Data were analysed by SPSS statistical analysis for Windows version 22.0 (IBM Corp, Armonk, NY). Data of peak force and velocity were compared by One-way ANOVA tests whereas the damping times were compared by Bonferroni's method. Damping conditions were analysed to find a significant effect of the impact position on the damping process.

Results

Peak force (Figure. 4)

For centre impacts, the peak force at the grip was 111.6±1.5 N when no damper was attached. When the button damper was installed, the peak force was 109.9±0 N, while it was 108.2±1.5 N when the worm damper was installed. One-way ANOVA tests showed that neither damper significantly reduced the peak force ($p = 0.098$).

For above-centre impacts, the peak force at the grip was 110.7±3.0 N with no damper, 111.4±4.0 N with the button damper and 109.0±1.5 N with the worm damper. Neither damper significantly reduced the peak force ($p = 0.587$).

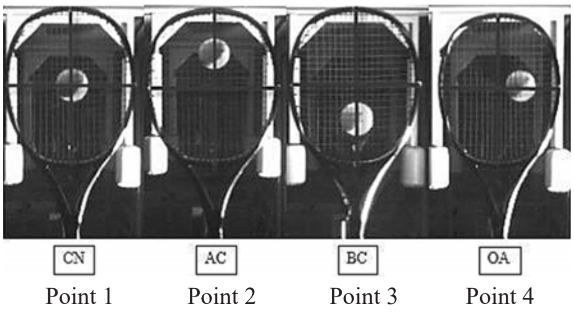

Figure 2. Determining ball impact location using high speed camera. Point 1 was the geometric centre of the string bed (CN). Point 2 was 6 cm above the CN (AC). Point 3 was 6 cm below the CN (BC). Point 4 was 6 cm to the right of the CN (off-axis, OA).

Figure 3. Rackets installed with a button damper (L) and a worm damper (R).

For below-centre impact, the peak force at the grip was 99.4±5.2 N with no damper, 99.4±5.2 N with the button damper and 100.3±1.5 N with the worm damper. Neither damper significantly reduced the peak force ($p = 0.629$).

For off-axis impact, the peak force at the grip was 135.1±4.0 N with no damper, 135.1±4.0 N with the button damper and 130.8±2.6 N with the worm damper. Neither damper significantly reduced the peak force ($p = 0.228$).

The peak force was the highest for off-axis impact and the lowest for below-centre impacts for every damper condition ($p<0.001$).

Damping time (Figure. 5)

For centre impacts, the damping time was 246.9±11.5 ms without a damper, 236.7±12.5 ms with the

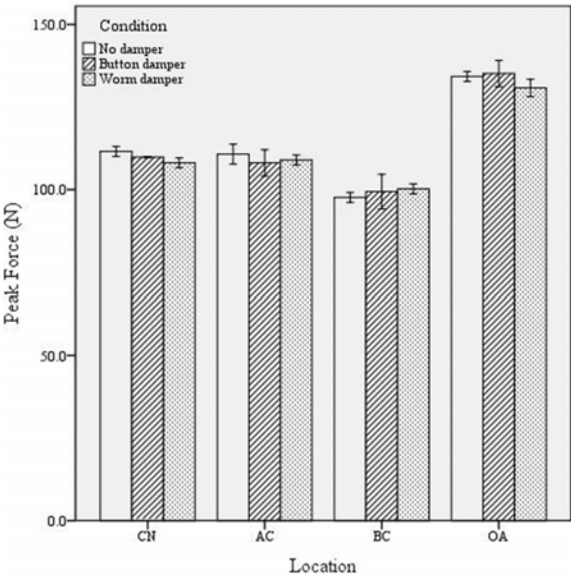

Figure 4. Peak force (Newton) at various damping conditions and various impact locations. Both dampers did not reduce the impact force at the grip, regardless of the impact position (CN = center, AC = above center, BC = below center, OA = off-axis).

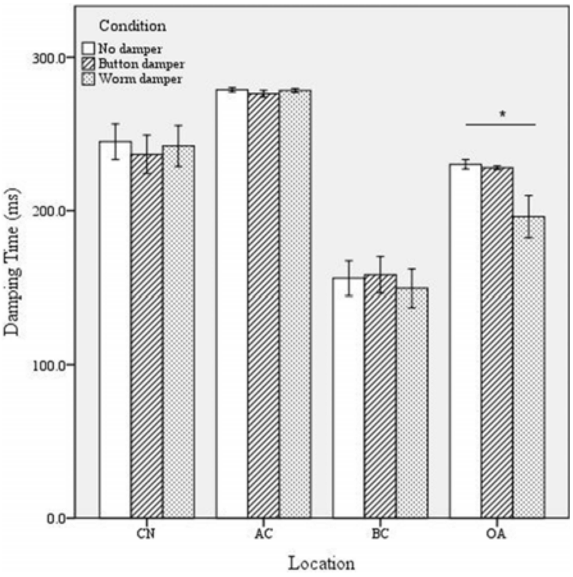

Figure 5. Damping time (millisecond) with various damped conditions and various impact locations. The worm damper significantly reduced the damping time at off-axis impact, in comparison with the other two conditions (p = 0.004) (CN = center, AC = above center, BC = below center, OA = off-axis).

button damper, and 242.2±13.4 ms with the worm damper. Neither damper significantly reduced the damping time ($p = 0.727$).

For above-centre impact, the damping time was 278.8±1.4 ms with no damper, 276.3±1.3 ms with the button damper, and 278.3±1.3 ms with the worm damper. Neither damper significantly reduced the damping time ($p = 0.216$).

For below-centre impact, the damping time was 156.0±11.3 ms without a damper, 158.3±11.8 ms with the button damper, and 149.6±12.4 ms with the worm damper. Neither damper significantly reduced the damping time ($p = 0.666$).

For off-axis impacts, the damping time was 230.2±3.1 ms with no damper, 227.9±1.2 ms with the button damper, and 196.1±13.8 ms with the worm damper. The worm damper significantly reduced the damping time in this condition, in comparison with the other two conditions ($p = 0.004$). Using the Bonferroni method, worm dampers significantly reduced the damping time by 15% or 34.2 ms compared to using no damper ($p = 0.002$). It was also found that worm dampers significantly reduced the damping time by 31.89 ms which was more than that found using the button damper. There was no significant difference between the damping time when using either the Button damper or no damper ($p = 1.0$).

Discussion

This was the first study that tested dampers with a high racket velocity and examined the manner in which the impact location affects the damper's effectiveness. Factors that may affect the force at the grip, such as, the type of racket, racket speed, string material, string tension, stroke, type of ball, and ball impact location were controlled. To avoid wind conditions, the experiments were conducted indoors. We used TESMA simulating machine to generate the strikes so we could precisely determine the impact of the tennis ball on the string bed. Impacts were precisely located on the string bed of the racket by adjusting the timing between the ball release above the striker and the angular position of the racket rotating at a pre-determined constant speed. The effect on rotational torque was studied by hitting the ball at an off-axis location, which has never been applied for damper testing.

Peak force

The shape of the damper (whether button or worm) did not significantly reduce the peak force at the handle (p>0.05) for any impact position. The highest peak force occurred for off-axis impacts, while the lowest peak force occurred for below-centre impacts. Similar to the findings of Henning, the present study showed that off-centre impacts increased the force on the wrist more than centre impacts. Because of a very small mass (5 to 20 g) of the damper compared to the tennis racket (300 g), this prevented dampers from significantly altering the force transmitted to the wrist.

Damping time

For off-axis impacts that caused torsion force at the grip, the worm damper significantly reduced the damping time at the grip by 15%. This was the first report showing a significant reduction of Damping time in a realistic situation. Our results were consistent with the report of Ameer et al that that the damper reduced the myoelectric activity of the wrist extensor muscle only for less experienced (1 to 2 years) players as it is possible that such players frequently stroke the ball at an off-axis position(15). Substantial increases in the wrist flexion/extension torque were found for off-centre impact locations(16,27). The worm damper's reduction of the damping time in this case would reduce the wrist muscle myoelectric activity.

The difference findings of the 2 damper shapes may be due to the numbers of attached strings in each type of damper. The worm damper which has several strings attachment resulting in the more stability when impacted by stroke than that found in the button damper which had only 3 strings attachment.

The process that the present study clamped the racket to the stroke simulator was our limitation. When the TESMA is driven at 450 rpm, the handle must be clamped to the machine rigidly to prevent the racket from falling off. In practice, players' palms are flexible; therefore, the grip on a tennis racket is also flexible. Different models of tennis rackets will bend when hitting the ball and will vibrate differently. In addition, the sensor used in this experiment was a force sensor that measured only in a single plane; therefore, only the force on one side of the racket handle was measured. In practice, vibrations are spread around the racket handle on all sides.

Conclusion

This experiment found that a worm damper, but not the button damper, can significantly reduce the damping time when hitting the ball at an off-axis location. The players especially the less experienced players may consider the use of worm dampers for this purpose. Neither damper reduces the damping time when the ball strikes at an axially aligned location nor do they reduce the peak force when installed at any location. The dampers may be used for other reasons, such as, noise reduction, ball control or comfort from some other effect. Further study could help reveal the physical mechanisms that assess the preference of players for dampers.

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What is already known on this topic?

The effectiveness of damper for reduction of force and vibration is a controversial issue. No studies have investigated the effects of different damper shapes in different impact locations on the string bed.

What this study adds?

Worm dampers can reduce the duration of post-impact racket handle vibrations.

Potential conflicts of interest

The authors declare no conflict of interest.

References

1. Dines JS, Bedi A, Williams PN, Dodson CC, Ellenbecker TS, Altchek DW, et al. Tennis injuries: epidemiology, pathophysiology, and treatment. J Am Acad Orthop Surg 2015;23:181-9.
2. Hutchinson MR, Laprade RF, Burnett QM, Moss R, Terpstra J. Injury surveillance at the USTA Boys' Tennis Championships: a 6-yr study. Med Sci Sports Exerc 1995;27:826-30.
3. Pluim BM, Staal JB, Windler GE, Jayanthi N. Tennis injuries: occurrence, aetiology, and prevention. Br J Sports Med 2006;40:415-23.
4. Abrams GD, Renstrom PA, Safran MR. Epidemiology of musculoskeletal injury in the tennis player. Br J Sports Med 2012;46:492-8.
5. Yoshizawa M, Kumamoto M, Nemoto Y, Itani T, Jonsson B. Effects of dynamic features of tennis rackets on muscular load of tennis players. J Biomech 1989;22:1106.

6. Hennig EM, Rosenbaum D, Milani TL. Transfer of tennis racket vibrations onto the human forearm. Med Sci Sports Exerc 1992;24:1134-40.
7. Rogowski I, Creveaux T, Triquigneaux S, Mace P, Gauthier F, Sevrez V. Tennis racket vibrations and shock transmission to the wrist during forehand drive. PLoS One 2015;10:e0132925.
8. Chow JW, Carlton LG, Lim YT, Chae WS, Shim JH, Kuenster AF, et al. Comparing the pre- and post-impact ball and racquet kinematics of elite tennis players' first and second serves: a preliminary study. J Sports Sci 2003;21:529-37.
9. Hatze H. Forces and duration of impact, and grip tightness during the tennis stroke. Med Sci Sports 1976;8:88-95.
10. Li FX, Fewtrell D, Jenkins M. String vibration dampers do not reduce racket frame vibration transfer to the forearm. J Sports Sci 2004;22:1041-52.
11. Mohr S, Cottey R, Lau D, Gillet C, Kotze J, Jolly M, et al. Dynamics of a string-bed damper on tennis rackets (P175). In: Estivalet M, Brisson P, editors. The engineering of sport 7. Vol. 2. Paris: Springer Paris; 2008. p. 179-89.
12. Stroede CL, Noble L, Walker HS. The effect of tennis racket string vibration dampers on racket handle vibrations and discomfort following impacts. J Sports Sci 1999;17:379-85.
13. Timme N, Morrison A. The mode shapes of a tennis racket and the effects of vibration dampers on those mode shapes. J Acoust Soc Am 2009;125:3650-6.
14. Tomosue R, Sugiyama, K., Yoshinari, K. and Yamamoto,K. The effectiveness of damping material in reducing impact shock in the tennis forehand drive. In: Reilly T, Hughes M, Lees A, editors. Science and racket sports. London: Taylor & Francis; 1995. p. 140-5.
15. Ameer MAA, El-hafez SM, El-hafez GM, Abdalla AAA. Effect of string vibration damper on the myoelectric activity of the wrist extensors. Int J Curr Res 2015;7:14656-61.
16. King MA, Kentel BB, Mitchell SR. The effects of ball impact location and grip tightness on the arm, racquet and ball for one-handed tennis backhand groundstrokes. J Biomech 2012;45:1048-52.
17. Li L, Yang SH, Hwang C-S, Kim YS. Effects of string tension and impact location on tennis playing. J Mech Sci Tech 2009;23:2990-7.
18. Choppin S. An investigation into the power point in tennis. Sports Eng 2013;16:173-80.
19. NaB D, Hennig EM, Schnabel G, editors. Ball impact location on a tennis racket head and its influence on ball speed, arm shock and vibration. ISBS-Conference Proceedings Archive. Konstanz, Germany; 1998.
20. Engel J. Tennis: dynamics of racket-grip interaction. J Hand Surg Am 1995;20(3 Pt 2):S77-81.
21. Mohandhas BR, Makaram N, Drew TS, Wang W, Arnold GP, Abboud RJ. Racquet string tension directly affects force experienced at the elbow: implications for the development of lateral epicondylitis in tennis players. Shoulder Elbow 2016;8:184-91.
22. Pavilas C, Suwanthada S, Chaiwatcharaporn C. The Tennis strike simulation machine identified and confirmed power spot location on tennis racket during flat first serve. J Exerc Physiol Online 2015;18:14-26.
23. Pavilas C, Chaiwatcharaporn C. Comparison in maximumball velocity of 3-structural characteristic rackets using simulates tennis flat serve. J Sports Sci Tech 2014;14:1-16.
24. Hennig EM, Milani TL, Rosenbaum D. The influence of tennis racket design on impact induced arm oscillations. J Biomech 1994;27:669.
25. Hatze H. The effectiveness of grip bands in reducing racquet vibration transfer and slipping. Med Sci Sports Exerc 1992;24:226-30.
26. Nesbit SM, Elzinga M, Herchenroder C, Serrano M. The effects of racket inertia tensor on elbow loadings and racket behavior for central and eccentric impacts. J Sports Sci Med 2006;5:304-17.
27. Tomosue R, Mutoh Y, Yoshinari K, Kawazoe Y. Measuring the vibrations of a racket handle and the wrist joint in the tennis forehand drive. J Biomech 1992;25:719.