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Research article

The influence of ball velocity and court illumination on reaction time for tennis volley

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Abstract
The purpose of this study is to examine the effects of ball velocity, court illumination, and volley type on the reaction time (RT) of a tennis athlete for a volley stroke. Eights cases with two different ball velocities (high and low), two volley types (forehand and backhand) and two court illumination levels (dark and bright) were studied. The 30 participating subjects consisted of 18 male and 12 female college tennis athletes (age: 24 ± 3.2 *yr*), with a United States Tennis Association (USTA) ranking above 2.5. In order to ensure the validity of real-world correlations, the experiments were designed to simulate real competition situations. Reaction times were measured for volley strokes in response to different approaching ball velocities (high: 25.05±0.37 m/s and low: 17.56 ± 0.92 $m{\cdot}s^{-1}$) for several volley types (forehand and backhand) and court illumination levels (55649 ± 4292 lux and 363.24 ± 6.53 lux on the court). During the tests, the signals from an electromyogram sensor and a 3-axis accelerometer (±50 g) were recorded using an NI DAQ card (NI PXI-6251) and then analyzed to determine reaction time (RT), premotor reaction time (PRT), and motor reaction time (MRT) through the LabVIEW system. Subsequent 3-way ANOVA analysis indicated no RT, PRT, or MRT interaction between ball velocity, volley type and illumination. The ball velocity and illumination parameters did affect RT and PRT values significantly with $p < 0.05$, no significant variation in MRT was observed across any implemented experimental conditions. All experimental results indicate that ball velocity and illumination levels strongly affect the value of PRT, but have no significant effect on the value of MRT, the changes in RT were dominated by PRT.

Key words: premotor reaction time, motor reaction time, electromyogram, tennis.

Introduction

The volley is a striking technique often used by tennis athletes which plays a key role in competitive tennis tournaments. Executing the move correctly requires quick responses with minimal time delay due to the velocity of the ball and the physical proximity of the opponent (Shim, Chow, Carlton, and Chae, 2005); the reaction time (RT) of a player is thus the key to performance. A decreased RT affords a player more time to consider the proper execution of an appropriate movement.

The RT is defined as the interval between the onset of a signal and the initiation of a response (Magill, 2007). The duration of the RT is affected by several factors, but the most direct influences are external stimuli (Lin, 2001). A stimulus-response model can be defined to describe an athlete's reaction upon the reception of a visual stimulus. In terms of motor control, researchers assume that there are three stages in information processing. The first stage pertains to stimulus identification in response to sensory inputs. When this stage is completed, information is passed to the response selection stage and finally to the third stage, response programming, until an action (output) occurs (Schmidt and Wrisberg, 2004). Sources of stimuli such as a flying ball or court illumination may influence a player's information processing time. The time cost associated with each of these three stages determines the length of the RT.

RT can generally be divided into two components with the help of the electromyogram (EMG) signal – the premotor reaction time (PRT) and the motor reaction time (MRT). The PRT is the central process time between the input of a stimulus signal and the first detected changes in EMG. The MRT is the peripheral execution time between an initial increase in muscle activity and the occurrence of actual movement (Magill, 2007; Sheridan, 1981).

Previous studies have shown that ball velocity is one of the key external factors influencing RT (Liu, 2001; 2002; Owings et al., 2003). However, some of the studies were done in virtual reality utilizing a video analysis approach, thus limiting the validity of their correlation to real-world systems (Cheng, 2006; Su, 2006). Also, there are rare studies and discussions relating to PRT and MRT parameters.

The intensity of illumination is another external factor influencing RT and the reaction time is also dependent upon synaptic activity (Adrian, 1928). An athlete's RT is used to assess performance by gauging the speed with which a required movement is initiated as an indicator of likely success or failure. Reduced illumination induces the Purkinje shift and reduces visual acuity (Boyce, 1973). Also, optic nerve fibers discharge more readily and with greater frequency in response to bright stimuli (Hartline and Graham, 1932; Lines et al., 1984). Visual acuity under reduced illumination conditions varies significantly both tennis players and non-players (Jafarzadehpur and Yarigholi, 2004). This study probes the real effect of players' performance in different lighting environments.

This study was done in the field to obtain the parameters relating to RT. We examined the influence of different ball velocity, illumination level and volley type on the execution of a tennis volley, and identified the predominant factors influencing RT under these conditions.

Methods

Eighteen male and twelve female athletes of college

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tennis team (age: 24 ± 3.2 *yr*; height: 1.72 ± 0.05 *m*; weight: 68.3 ± 10.3 *kg*) with a United States Tennis Association (USTA) ranking above 2.5, were asked to perform the forehand and backhand volley movements. Each subject had normal vision or wore appropriate corrective lenses (the standard was VA=1.0) as tested by an ophthalmologist.

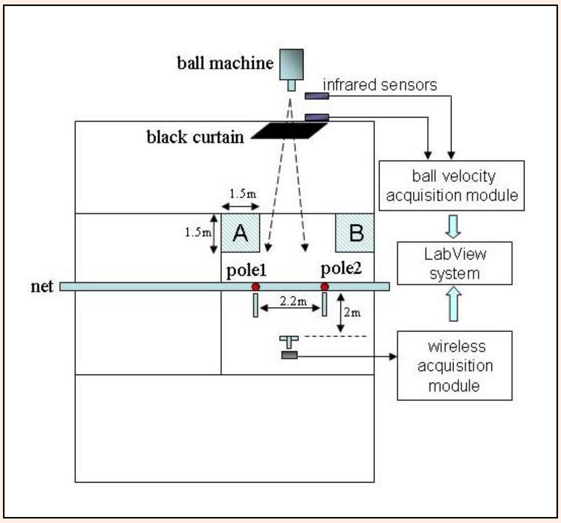

Figure 1. **The court layout for the experiment: the ball machine is blocked by a black curtain and located 12m from the net, the effective range between pole 1 and pole 2 is 2.2 m, the distance from the participant's ready line to the net is 2m. The zone A and B are the targets for the forehand and backhand volley.**

Two infrared sensors were connected to a data acquisition module (NI PXI-6251, sampling rate: 6 kHz) for ball velocity measurements. High velocity was defined as 25.05 ± 0.37 $m \cdot s^{-1}$, and low velocity was 17.56 ± 0.92 $m \cdot s^{-1}$ in this study (Chow et al., 1999; Andrew, Knudson, and Tillman, 2003). A wireless module (NI WLS-9163, sampling rate: 6 kHz) was used to obtain the signals from the EMG and accelerometer (Figures 1 and 2). The volley movement is characteristic by striking the ball with trunks and arms and the dominate joint is shoulder; also, the deltoid muscle displayed the greatest activity during the pre-test. Therefore, the EMG sensor was pasted on the deltoid muscle of athletes' dominate arm in this study (Tu, 2008). The accelerometer is attached to the top of the racket.

As measured from the center ground of the court using a digital light meter (TES-1332A), high illumination (HI) during the bright condition was 55640 ± 5108 *lux* and low illumination (LI) was 361.45 ± 1.28 *lux*. The contrast value of the ball was 8% in the HI situation and 19.4% in the LI situation (formula 1).

$$contrast \quad value = |Lux_1 - Lux_2| / Lux_1 \qquad \text{Eq 1}$$

The Lux_1 is the illumination that light meter measured toward the ball which on the center of tennis court ground (the height from the top of ball to the light meter sensor is 7 cm), Lux_2 is the illumination that light meter measured toward the ground.

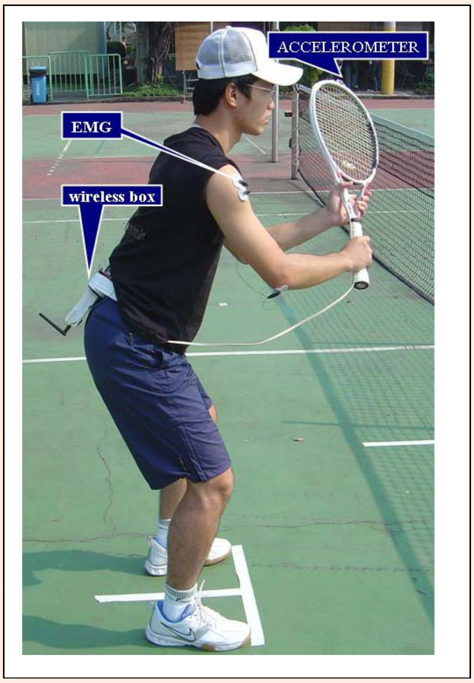

Figure 2. **Layout of sensors on the subject: the wireless box is fixed to the back of a participant's waist, the accelerometer is attached to the top of the racket, and the EMG sensor is taped to the deltoid of the dominant arm.**

All the acquisition modules were synchronized through LabVIEW system, to identify the RT parameters (Figures 1 and 3).

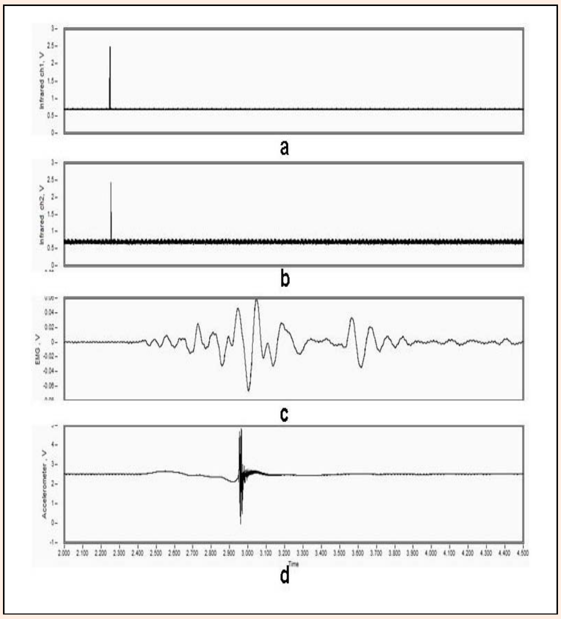

Figure 3. **Signals from the experimental system: (a) infrared sensor 1, (b) infrared sensor 2, (c) integral EMG, (d) accelerometer (sampling time 1/6000 s).**

In the tests, participants were randomly separated into two groups. One group was tested under high illumination first and then low illumination, while the other was

Table 1. Mean (±SD) of RT parameters for different ball velocities, volley types and illumination levels.

Independent Variables		High Ball Velocity		Low Ball Velocity	
		Forehand	Backhand	Forehand	Backhand
RT(s)	HI	.263 (.038)	.227 (.043)	.257 (.068)	.253 (.047)
	LI	.198 (.017)	.195 (.044)	.225 (.037)	.227 (.037)
PRT(s)	HI	.185 (.063)	.176 (.047)	.205 (.058)	.205 (.043)
	LI	.152 (.038)	.151 (.041)	.182 (.031)	.176 (.036)
MRT(s)	HI	.052 (.020)	.051 (.022)	.052 (.025)	.048 (.030)
	LI	.040 (.013)	.043 (.015)	.042 (.019)	.051 (.014)

tested in the reverse order to counterbalance each trial. There were 8 specific cases involved in every trial relating to each combination of two different ball velocities, two directions (for forehand and backhand strokes), and two different illuminations. To increase the statistical validity of the result, participants performed 5 successful tests for each of these 8 cases; 40 tests were carried out for each participant in the study, and the cases in each trial were arranged randomly. During the tests, participants stood behind the ready line and held the racket with their dominant hand in the ready-to-volley position as indicated in Figure 3. An advisor announced a ready signal before each ball was projected from the ball machine.

Because the RT is dependent on PRT and MRT, all three values were determined simultaneously during the tests. In this study, PRT was defined as the time period between tennis balls triggering the first infrared sensor and the onset of the deltoid's EMG signal; MRT was defined as the time period between the onset signals from the deltoid's EMG and the first accelerometer reading. To examine the influence of ball velocity and the court illumination on RT for the tennis volley, and to identify the predominant physical parameter impacting RT, the data generated was analyzed by a 3-way Analysis of Variance [ANOVA] (Knudson, 2009), the significance level of $\alpha = 0.05$ and the independent variables were ball velocity, illumination and volley type the dependent variables were RT, PRT and MRT.

Results

Effects of ball velocity, volley type and illumination on RT

The results of the 3-way ANOVA are shown in Tables 1 and 2. The RT was affected by different ball velocities ($F = 5.49$) and illuminations ($F = 26.23$), but had no significant effect by the different volley types ($p > 0.05$). The RT do not differ significantly under the interaction of volley type, ball velocity and illuminations ($p > 0.05$). It also indicates that the values of RT are largely independent of volley type, ball velocity and illuminations.

Effects of ball velocity, volley types and illuminations on PRT

The PRT was affected by different ball velocities ($F = 20.85$) and illuminations ($F = 24.28$), but has no significant effect by the different volley types. The PRT do not differ significantly under the interaction of volley type, ball velocity and illuminations ($p > 0.05$). It also indicates that the values of PRT are largely independent of volley types, ball velocities and illuminations (Table 3).

Corroborating the previous findings, the ball velocity was found to affect the values of RT ($F = 5.49$; Table 2) and PRT ($F = 20.85$; Table 3) significantly ($p < 0.05$), with no effect on MRT (Table 4). More importantly, the analysis shows that the values of RT ($F = 26.23$; Table 2) and PRT ($F = 24.28$; Table 3) were substantially affected by the illumination ($p < 0.05$), but this is not the case for the MRT.

Effects of ball velocity, volley types and illuminations on MRT

Finally, no significant change in the value of MRT ($p > 0.05$) was observed under varying ball velocities, volley types and illuminations (Table 4).

Table 2. Variance of RT with different velocities, volley types and illumination levels (s).

Source	SS	df	MS	F
S	.27676827	29	.00954373	
Ball Velocity(A)	.02372459	1	.02372459	5.49*
S*A	.12523422	29	.00431842	
Volley(B)	.00614679	1	.00614679	1.56
S* B	.11441265	29	.00394526	
Illumination(C)	.08979137	1	.08979137	26.23*
S* C	.09929178	29	.00342385	
Ball Velocity* Volley (A* B)	.00556797	1	.00556797	2.61
S*A* B	.06183147	29	.00213212	
Ball Velocity* Illumination (A* C)	.00571146	1	.00571146	2.72
S* A* C	.06093196	29	.00210110	
Volley* Illumination(B* C)	.00561837	1	.00561837	1.74
S* B* C	.09359095	29	.00322727	
Ball Velocity* Volley* Illumination(A* B* C)	.00262291	1	.00262291	0.91
S* A* B*C	.08403370	29	.00289771	
Total	1.05527845	239		

* p < 0.05

Table 3. Variance of PRT with different velocities, volley types and illumination levels (s).

Source	SS	df	MS	F
S	.19710519	29	.00679673	
Ball Velocity(A)	.04067969	1	.04067969	20.85*
S*A	.05657522	29	.00195087	
Volley(B)	.00098983	1	.00098983	.38
S* B	.07569195	29	.00261007	
Illumination(C)	.04471194	1	.04471194	24.28*
S* C	.05340871	29	.00184168	
Ball Velocity* Volley (A* B)	.00003010	1	.00003010	.05
S*A* B	.01931962	29	.00066619	
Ball Velocity* Illumination (A* C)	.00014137	1	.00014137	.41
S* A* C	.00996674	29	.00034368	
Volley* Illumination(B* C)	.00002220	1	.00002220	.01
S* B* C	.04642442	29	.00160084	
Ball Velocity* Volley* Illumination(A* B* C)	.00081181	1	.00081181	.83
S* A* B*C	.02834932	29	.00097756	
Total	.57422813	239		

* $p < 0.05$.

Discussion

Effects of ball velocity, volley type and illumination on RT

This analysis has several implications. Firstly, the RT of the athletes was shorter for high ball velocities compared with low velocities. This is likely due to the fact that better coordination between central processes and muscle contractions in a well trained athlete will be aroused when the incoming ball velocity is increased. This result agrees with previous studies; Williams and MacFarlane (1975) reported that the RT in male college students decreased with an increase in ball velocity for volley strokes. The numerical simulations of Liu (2001) also showed that the RT of soccer athletes decreased when the incoming ball velocity was increased.

In this study the RT value by forehand is shorter than backhand but there were not significant differences ($p > 0.05$) in RT under different volley types. Andrew(2003) showed a significant shorter RT for the forehand volley (14 ms) when compared to the backhand volley and the contrary result that backhand volley is shorter than forehand volley (John, 1999). The dissimilar results may caused by the different performance levels of subjects and the dissimilar target arrangements and movement type of steps.

The RT value in high illumination (bright) is longer than the low illumination (dark). Martens et al. (1996) showed in a field-experiment, that the reduction of the court illumination level in tennis lower than 200 lux causes a significant decrease in the accuracy of hits/strokes of the players (25% reduced hit-quota in a ball-machine-test). At increased illumination levels of more than 400 lux (up to 900 lux) a general trend towards raised hit-quotas was determined. In this study, the illuminations were sufficient for the performance (high illumination: 55635 lux, low illumination: 336 lux).

The RT values obtained under different illumination levels were significantly varied ($p < 0.05$). For both high and low ball velocities, RT was faster at LI relative to HI measurements. This result may be directly related to the level of attention required to complete the tests under each set of conditions. Participants had to pay more attention at LI levels than HI situation. The influence of attention on response time has been studied in relation to baseball catching by Owings et al. (2003), who showed that RT values were significantly shorter when subjects were in a fully attentive condition compared with subjects whose attention was split. It is a limitation of the present study, that the level of attention was not analyzed. Maybe,

Table 4. Variance of MRT with different velocities, volley types and illumination levels (s).

Source	SS	df	MS	F
Ball Velocity(A)	7.6291004E-6	1	7.6291004E-6	.02
S*A	.01435372	29	.00049496	
Volley(B)	.00001215	1	.00001215	.04
S* B	.00998857	29	.00034443	
Illumination(C)	.00142686	1	.00142686	3.89
S* C	.01063019	29	.00036656	
Ball Velocity* Volley (A* B)	.00034991	1	.00034991	1.24
S*A* B	.00816032	29	.00028139	
Ball Velocity* Illumination (A* C)	.00017577	1	.00017577	.42
S* A* C	.01208792	29	.00041682	
Volley* Illumination(B* C)	.00039273	1	.00039273	1.02
S* B* C	.01120045	29	.00038622	
Ball Velocity* Volley* Illumination(A* B* C)	.00076752	1	.00076752	2.35
S* A* B*C	.00945517	29	.00032604	
Total	.10048447	239		

whose attention was split. It is a limitation of the present study, that the level of attention was not analyzed. Maybe, there is an circadian effect of time of day.

The measured RT was faster for high ball velocities. In terms of human psychology, different ball velocities could potentially be interpreted as disparate stimuli (Pianta and Kalloniatis, 1998). With the increased stimulus intensity associated with high ball velocities, simple RT decreased.

Effects of ball velocity, volley types and illuminations on PRT

This result is consistent with the studies of Pan et al. (2001) and Ma and Trombly (2004) which demonstrated that change in RT was due to change in PRT. Participants paid more attention, and this accelerated central information processing when balls were approaching at a high velocity. The PRT values measured under different illumination conditions varied significantly ($p < 0.05$), the PRT for volley strokes under both high and low ball velocities was faster at LI than during HI situation. Davranche et al. (2006) found that the mean PRT was longer with external weak visual intensity than with strong visual intensity. Pre-motor processes under conditions of weak visual intensity were negatively affected by prior exercise. Optic nerve fibers discharge more readily and with greater frequency in response to bright stimuli (Hartline and Graham, 1932). The visual intensity of a fluorescent yellow tennis ball was stronger under LI than HI, and PRT was thus faster at LI. Furthermore, the tennis ball with bright yellow color in the LI court (contrast value=19.8%; formula 1) had higher contrast value than in the HI court (contrast value = 8%; formula 1) which led the subjects to identify the ball with shorter PRT. Therefore, higher attention levels at LI coupled with the contrast of the ball with the court may facilitate the process of stimulus identification.

Effects of ball velocity, volley types and illuminations on MRT

This result revealed that the impulse transmission time from the central nervous system to the deltoid of a well trained athlete is relatively stable, regardless of any change in the ball velocities, volley types and illuminations. In any event, PRT levels are sufficiently robust to compensate for minor alterations in MRT (Sheridan, 1984). It was not an unexpected result that motor unit recruitment of an athlete be synchronous rather than asynchronous in response to a fairly rapid movement requirement (Evarts, 1979). Participants in the study were majors in physical education who possessed varied athletic specialties but roughly equivalent physical conditions; in this group, no significant difference in MRT was evident. Pan et al. (2001), Davranche et al. (2006), Lines et al. (1984) also found that motor time was not influenced by signal intensity.

Martens et al. (1996) showed in a field-experiment, that the reduction of the court illumination level in tennis lower than 200 lux causes a significant decrease in the accuracy of hits/strokes of the players (25% reduced hit-quota in a ball-machine-test). At increased illumination levels of more than 400 lux (up to 900 lux) a general trend towards raised hit-quotas was determined. Campbell et al. (1987) indicated the same view point. In this study, the subjects performed the volley movements skillfully in the different situations beyond the illumination level of 200 lux but the same RT related parameters were discovered. (Martens et al., 1996).

Conclusion

The RT and PRT for high ball velocities were faster than low ball velocities. The RT and PRT values at LI were faster than HI. MRT did not vary significantly under any experimental conditions. The duration of RT was mainly influenced by central information processing speed, and the peripheral process time remained stable. Ball velocity and illumination levels were the principal factors affecting the duration of RT. Results strongly suggest that changes in RT were dominated by PRT; in light of this correspondence, it is clear that the ability to sense visual stimuli may be enhanced by proper training and practice.

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Key points

- RT can generally be divided into two components with the help of the electromyogram (EMG) signal – the premotor reaction time (PRT) and the motor reaction time (MRT).
- The purpose of this study is to examine the effects of ball velocity, court illumination level, and volley type on the reaction time (RT) of the tennis athlete for volley strokes.
- Results strongly suggest that changes in RT were dominated by PRT; in light of this correspondence, it is clear that the ability to sense visual stimuli may be enhanced by proper training and practice.

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