Video Analysis Application to Assess the Reaction Time in an ATP Tennis Tournament

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Abstract: 2D Video analysis is often used in tennis to analyze the players' technique or issues related to game tactics. This paper applies video analysis to assess the reaction time in tennis matches. Fifteen subjects were examined (26.20 ± 4.75 years old, weight 79.13 ± 5.67 kg, height 184.40 ± 5.30 cm, BMI 23.26 ± 1.19), all with an ATP ranking between the #130 position and the #1066 position updated on the day of the sampling. The average RT was 0.248 ± 0.07 s. The longer reaction times were recorded at the first stroke after the serve, while the shorter were in defensive situations when the opponent was attacking or playing a volley, and the examined player often anticipate by starting the mouvement even before the opponent's stroke. The reaction times of high-level tennis players were found to be very short, often less than 120ms in defensive actions. These results prompt us to consider the importance of kinetic perceptual skills such as reaction speed and anticipation in tennis training.

1 INTRODUCTION

In tennis, many physical and mental (Casale, 2003; Castellani Alberto et al., 1996; Cei Alberto, 2015;) abilities are involved in the performance of high-level athletes, who are called upon to solve complex motor problems in a short-time through sprints and explosive actions often performed in precarious balance (Issurin, 2010; Matveev, 2001). Indeed, it appears that, by the tennis players' performance model, various coordinative and perceptive kinetic abilities, such as reaction, anticipation, and transformation, play a fundamental role (Fox et al., 1993; Schönborn, 1999). Scanning signals in advance, such as understanding the spot on the court where the opposing tennis player is about to address the ball, allow one to be in the right place and at the right time to mechanically implement and promote attack strategies (Singer & Negri, 1984). Reaction ability is the coordinative ability to react quickly (as quickly as possible) and correctly to given stimuli. The reaction time (RT) is the latency period between the occurrence of a stimulus and its response action (Koch et al., 2018; Schmidt & Lee, 2019; Sternberg, 1969), and is given by five components:

a. production of a stimulus in the sensory receptor;
b. transmission of the stimulus to the Central Nervous System;
c. processing (evaluation of the stimulus, choice of response, and formation of the effector signal);
d. sending effector signal to the muscle;
e. muscle response (Janssen, 2015; Zelaznik, 1996).

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Simple and *choice* RT can be achieved in sports. In the first case, the reaction is predefined, and a precise and well-known motor plan corresponds to the stimulus. *Simple* RT is often automated, and thus any processing time is absent (it involves eliciting simple conditioned reflexes to decrease the period between stimulus and response). During *choice* RT, it is necessary to perform a counter action appropriate to the situation, which is unexpected, that is being determined. The *choice* RT is always longer than the *simple* RT because there is a cognitive-rational processing phase between the perception of the stimulus and the execution of the motor action. In particular, it depends on the number of variables, that is, the number of possible stimulus-response alternatives. HICK's law describes the relationship between the logarithm of the number of stimulus-response options and RT; it shows that as the number of stimulus-response pairs increases, RT increases proportionally (Janssen, 2015; Proctor & Schneider, 2018). In reading the INPUT, being able to choose, among many, the most helpful information is a more relevant cognitive factor, which can allow for early reading of what is about to happen. That is why in the competition, the perception can occur before and during the stimulus. Motor anticipation is the ability to intuit a movement from the form of the action that precedes it (Meinel et al., 1984). There are two forms of motor anticipation, and the first is based on the experience of prior game situations, such as an opponent's tendency to serve wide from the left can prompt the responding player to anticipate the move, or visual anticipation, which is based on the visual reading of the opponent's movement. Visual anticipation is the ability to make accurate predictions from partial or incomplete visual information (Montagne et al., 2008). Examples of such information might be the direction of a player's gaze as they are about to shoot a penalty, the tennis player's throwing of the ball on serve, the position of the feet, or the movement of the racket and trunk before impact (Shimizu et al., 2019). In other disciplines, such as basketball, it has been found that athletes more successfully predict the direction of free throws to the basket with greater anticipation and accuracy than other individuals (like coaches or sports journalists and novices) (Aglioti et al., 2008). Visual anticipation is fundamental in the motor response process of the tennis player and is proportional to the athlete's level of experience. In recent years, some research has been conducted to understand what factors most influence these perceptual processes in sports. In studies performed with spatial occlusion of the opponent's body parts (legs, trunk, arms, and racket, etc.) worse accuracy and slower response times were found in videos with occlusion of the ball and trunk (Costa et al., 2023). Anticipation can also be observed in an isolated act, such as correctly predicting the speed and placement of a thrown object (e.g., a ball) that allows the athlete to be in the right place to repel or intercept it (Meinel et al., 1984; Shimizu et al., 2019). During training, reaction and anticipation skills can be trained with the help of new technological aids (Senatore & Buzzelli, 2022). Several research studies on reaction speed have been conducted in the last two decades, and various off-field measurement tools exist. However, there is not as extensive a description of systems for measuring reaction speed during competition, at least in tennis. Video-based methods for testing RT have been used successfully in some sports, such as karate, in previous publications (Mudric et al., 2015).

2 METHODS

This paper uses video analysis to measure and evaluate RT in tennis matches made by fifteen male professional players during the ATP Challenger "Castel del Monte" tournament in November 2022 (ATP Tour, 2022), played on indoor hard court surface, with Artengo TB930 balls. The sample of players had an age of 26.20 ± 4.77 years, weight of 79.13 ± 5.67 kg, height of 184.40 ± 5.30 cm, and body mass index of 23.26 ± 1.19. All subjects had an ATP ranking between the #130 and #1066 positions updated on the day the measurements were done. The analysis was conducted using video analysis software (*BIOMOVIE ERGO*, 2023) on video acquired at 240 fps by a WOLFANG Action Camera that was placed behind the central court. For the measurement of RT, the time between the impact of the opposing player and the first movement of the examined player was measured (the first movement coincides with the rotation of the shoulder line in the direction of the displacement, of the foot descending from the split-step or with a counter-movement of the contralateral leg). The impact of the opponent (the starting point of the ball) was taken as the zero point in the timeline because it is the stimulus to which the player reacts. The player's first movement is mainly evidenced by the rotation of the inside foot in the direction of the displacement on landing or in the moments immediately following the split step (Fish, 1983).

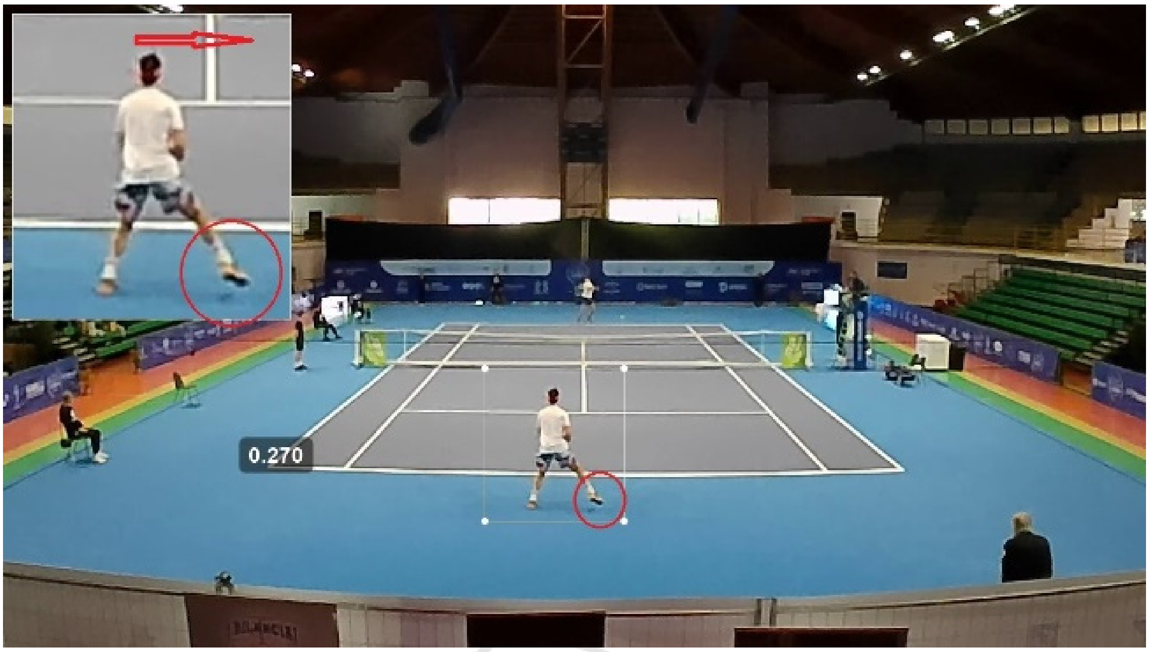

Figure 1: First movement lateral shift to the right.

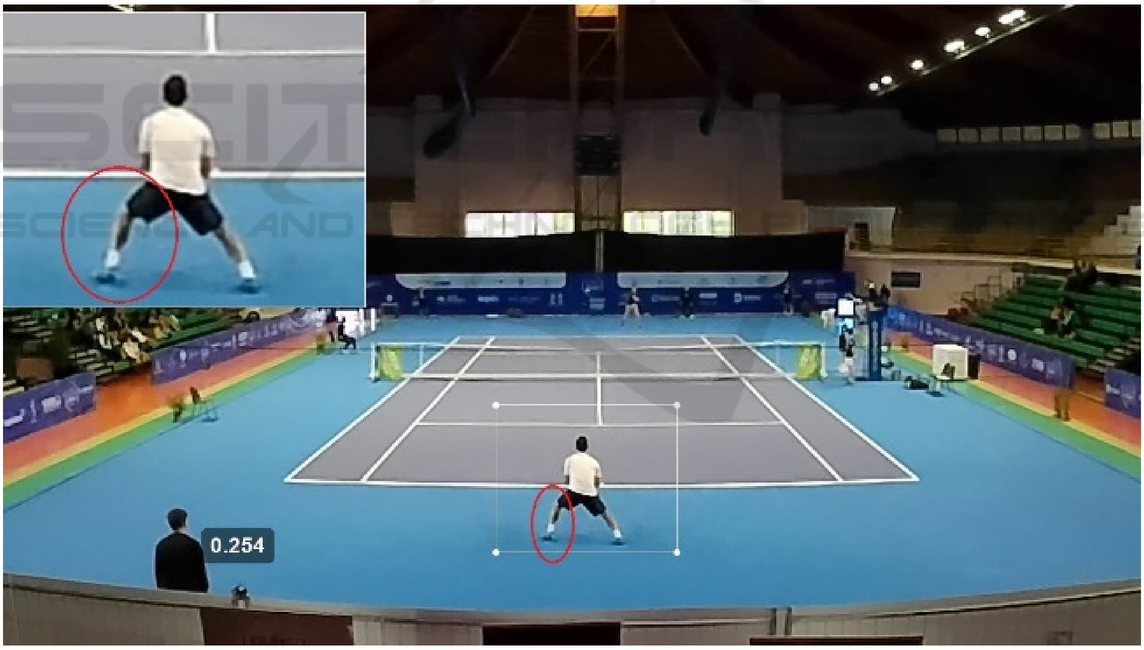

Figure 2: First movement lateral shift.

This shift can occur in the direction of the displacement or in the opposite direction to unbalance the weight of the body in that direction (counter-movement) with either the inside or outside foot (Figure 1, Figure 2) (Vuong et al., 2022). Four main types of step patterns are encountered: the Jab Step (Figure1, Figure3d), Pivot Step (Figure2), Gravity Step, and Counter Step (Figure3f). The Jab Step tends to be the most common and most efficient in small movements, and the Counter Step, on the other hand, has been found by recent studies to be the most effective in jerking to retrieve difficult balls (Vuong et al., 2022).

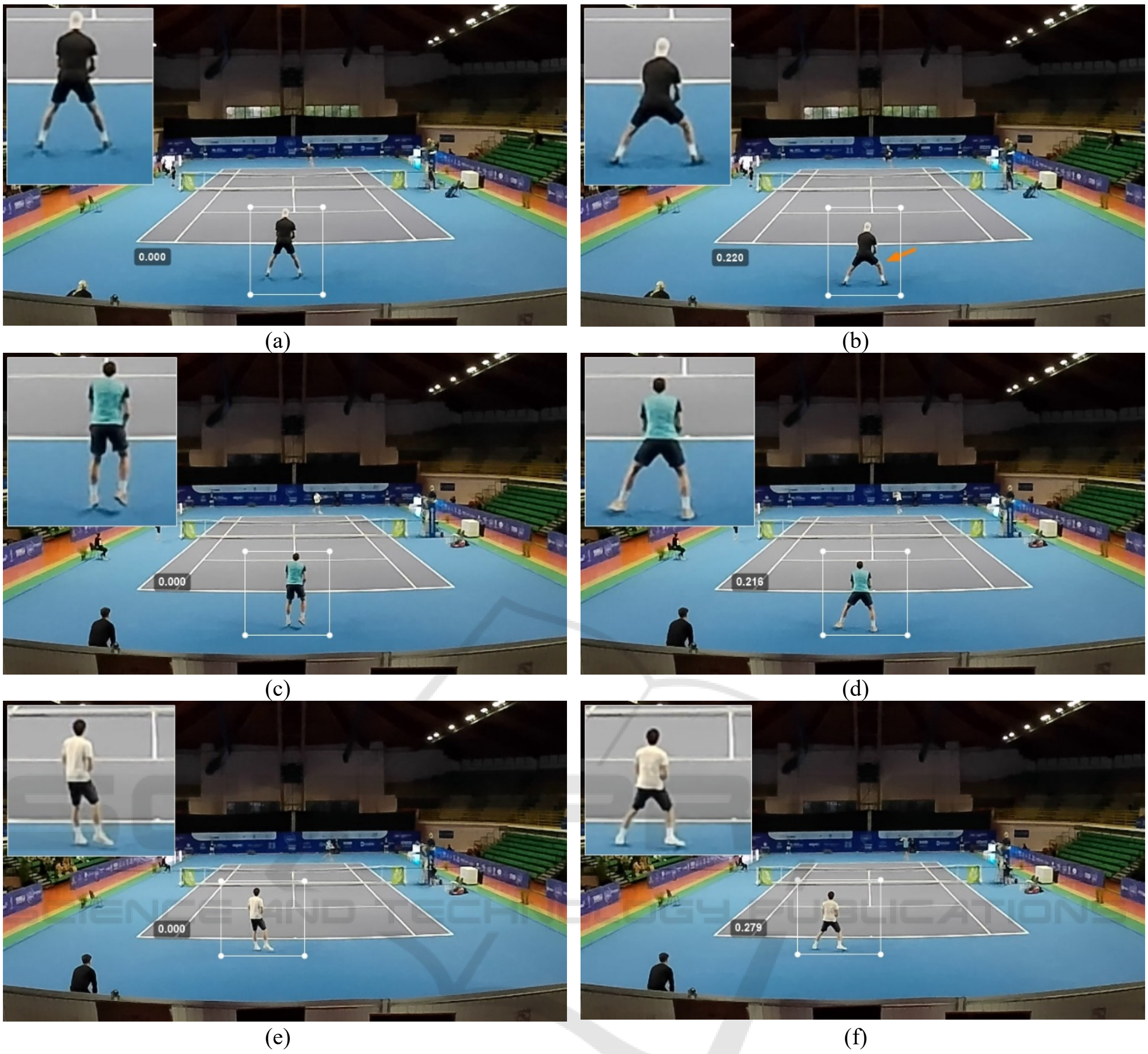

Figure 3: (a), (c), and (e) flight phase during the split step of three different players; (b), (d), and (f) first movement.

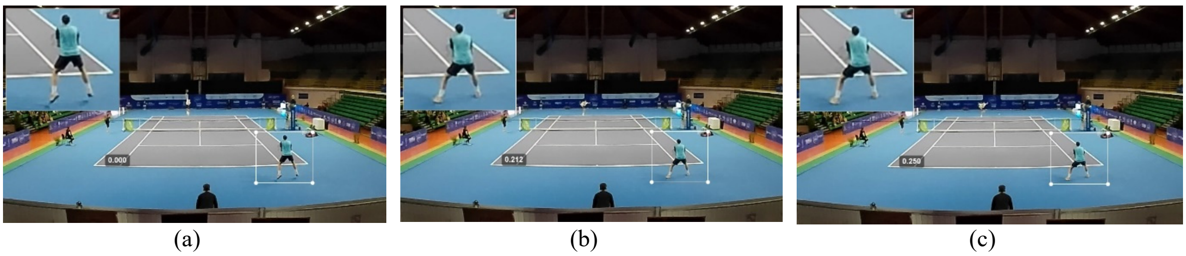

Figure 4: First displacement detected by racket movement in response shot: a) split step, b) landing, c) first movement.

In other cases, the first movement is evidenced by the rotation of the shoulders (UNIT-TURN) (Fish, 1983; Groppel et al., 1986) or the opening of the racket (Figure 4). In this case, the first movement (UNIT TURN) is calculated when the racket begins to move in the direction of displacement, i.e., to the right for forehand and to the left for backhand in right-handers, and vice versa for left-handers. The timer function of the video analysis software was used to measure reaction times. Twenty game situations were analyzed (all by the same examiner), mixed between rallies, serve response, first shot after serve, attack/defense, and volley play for each player. Single factor ANOVA was used to compare the means between the diffentent game situations. Pearson's correlation coefficient was used to compare the correlation between reaction time and player ranking, and the t-test was used to examine the statistical significance of the difference between two groups of players distinguished by ATP ranking.

3 RESULTS

Since the opponent's impact gives time zero in the timeline, negative values were found when the player anticipates the movement (Table 1). The average RT was 0.248 ± 0.07 s, correlating perceptibly with playing level. Specifically, the correlation index was found to be a trivial 0.15. The ten tennis players with ATP rankings between #130 and #400 had an average RT of 0.246 ± 0.07 s, and the subjects with rankings between #400 and #1066 had an average RT of 0.250 ± 0.07 s (Figure 5).

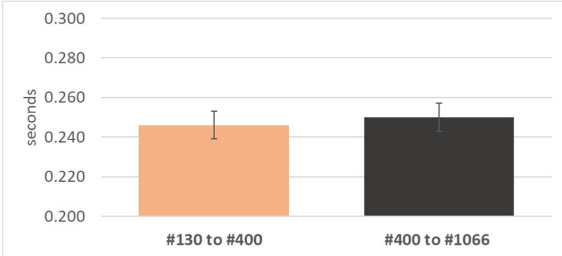

Figure 5: Average RT in players with ATP rankings between #130 to #400, and subjects with rankings between #400 to #1066).

The longest RTs were recorded at the first stroke after the serve, averaging 0.280 ± 0.05 s (0.278 ± 0.05 s for players with better ranking and 0.282 ± 0.05 s for the second group). The shortest in defensive situations when the opponent was attacking or playing a volley and the player examined anticipate by starting the move even before the opponent's stroke at times. In this case, they averagely reacted in 0.069 ± 0.18 s (Figure 6).

Table 1: Measurement of RTs in the fifteen players examined. Text color refers to: black = baseline rally, red = return, green = 1st shot after serve, light blue = opponent volley, purple = volley.

Player		**ATP Challenger Castel del Monte 2022**					Measurements of reaction time							
#	**Weight**	**Height**	**Age**	Ranking ATP	**Best Rank**		**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
1	78	185	26	130	Singles	105	0.245	0.212	-0.250	-0.108	0.383	0.308	0.320	0.237
2	82	185	18	251	Singles	246	0.270	0.241	0.245	0.325	0.258	0.300	0.220	0.245
3	84	191	25	277	Singles	272	0.220	0.212	0.241	0.354	0.200	0.154	0.312	0.266
4	86	191	28	286	Singles	211	0.245	0.170	0.279	0.204	0.233	0.254	0.187	0.225
5	82	185	28	293	Doubles	271	0.204	0.270	0.204	0.275	0.220	0.279	0.250	0.313
6	81	185	29	295	Singles	262	0.262	0.270	0.295	0.250	0.241	0.200	0.175	0.270
7	73	188	25	323	Singles	220	0.200	0.254	0.337	0.366	0.220	0.258	0.208	0.366
8	78	185	20	334	Singles	261	0.325	0.337	0.375	0.175	0.362	0.345	0.233	0.325
9	87	185	35	423	Singles	49	0.270	0.229	0.275	0.266	0.362	0.212	0.270	0.254
10	77	188	26	442	Singles	259	0.295	0.316	0.254	0.258	0.200	0.262	0.245	0.320
11	80	188	23	452	Singles	313	0.304	0.245	0.287	0.258	0.308	0.250	0.287	0.350
12	86	185	36	479	Singles	33	0.245	0.129	0.237	0.250	0.270	0.266	0.179	0.300
13	70	175	24	575	Singles	557	0.229	0.250	0.166	0.325	0.175	0.220	0.195	0.212
14	70	175	26	602	Singles	536	0.245	0.225	0.220	0.212	0.216	0.229	0.295	0.204
15	73	175	24	1066	Singles	1027	0.262	0.275	0.229	0.208	0.260	0.237	0.245	0.200

Measurements of reaction time														
#9	**#10**	**#11**	**#12**	**#13**	**#14**	**#15**	**#16**	**#17**	**#18**	**#19**	**#20**	**Average**	**Median**	**Stand. Dev.**
0.250	0.333	0.266	0.287	0.195	0.262	0.258	0.183	0.262	0.270	0.208	0.287	0.220	0.260	0.15
0.241	0.283	0.258	0.208	0.333	0.258	0.270	0.341	0.125	0.250	0.245	0.241	0.258	0.254	0.05
0.166	0.183	0.104	0.233	0.200	0.225	0.270	0.208	0.137	0.354	0.187	0.204	0.222	0.210	0.07
0.229	0.254	0.225	0.258	0.233	0.250	0.245	0.191	0.212	0.204	0.237	0.287	0.231	0.233	0.03
0.220	0.300	0.191	0.325	0.183	0.241	0.258	0.233	0.329	0.108	0.295	0.337	0.252	0.254	0.06
0.237	0.200	0.220	0.283	0.270	0.195	0.233	0.241	0.183	0.237	0.245	0.300	0.240	0.241	0.04
0.250	0.370	0.216	0.266	0.241	0.237	0.412	0.187	0.250	0.270	0.283	0.266	0.273	0.256	0.06
0.229	0.345	0.254	0.275	0.250	0.216	0.308	0.262	0.150	0.250	0.158	0.258	0.272	0.260	0.07
0.245	0.266	0.200	0.241	0.333	0.358	0.237	0.304	0.295	0.212	0.366	0.283	0.274	0.268	0.05
0.279	0.291	0.279	0.325	0.283	0.250	0.295	0.225	0.250	0.220	0.325	0.170	0.267	0.271	0.04
0.270	0.258	0.158	-0.187	0.250	0.258	0.287	0.270	0.245	0.283	0.250	0.258	0.244	0.258	0.11
0.270	0.212	0.166	0.258	0.283	0.291	0.300	0.225	0.250	0.354	0.291	0.216	0.250	0.254	0.05
0.262	0.258	0.250	0.233	0.258	0.241	0.262	0.220	0.237	0.208	0.245	0.250	0.235	0.239	0.03
0.220	-0.060	0.000	0.233	0.300	0.191	0.320	0.187	0.254	0.254	0.329	0.325	0.220	0.227	0.10
0.208	0.245	0.275	0.233	0.254	0.254	0.245	0.291	0.370	0.241	0.291	0.362	0.259	0.250	0.04
											Average:	0.248	0.250	0.07

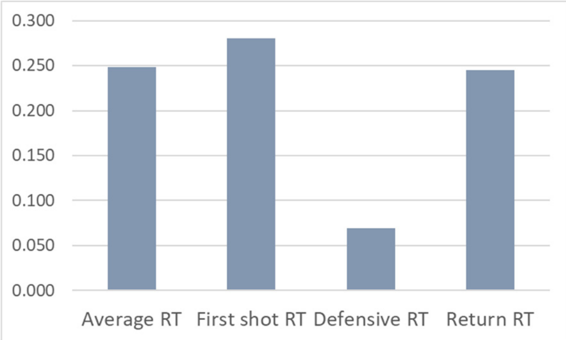

Figure 6: General average RT, in first-shot situations after serve, defense, and return.

Although the best RTs occurred in defense situations, the players' move did not always occur in the correct direction, because the anticipation has a relative margin of error. Due to any fast wrist movement until the impact, even a few milliseconds before, everything can change. In the serve response phase, RT was close to the average value of 0.245 ± 0.03 s. The average RT in response in tennis players with ATP rankings between #130 and #400 was 0.242 ± 0.03 s, while in the second group with rankings between #400 and #1066 it was 0.248 ± 0.03 s (Figure7).

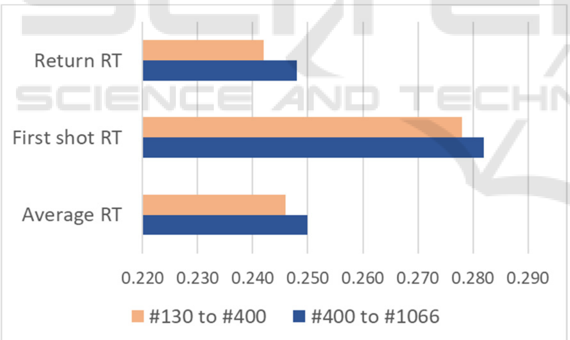

Figure 7: Average RT of various game situations in players with ATP rankings between #130 to #400 and in subjects with rankings between #400 to #1066.

The largest percentage difference between the two groups was found in the serve response situation. i.e., 2.48%. In the average, a more negligible difference in the order of 1.63% is shown (Figure 8). Although some differences were found in the two ranking groups, none of them was statistically significant. While the differences reaction times found in various game situations were found to be statistically significant at the ANOVA $p<0.001$.

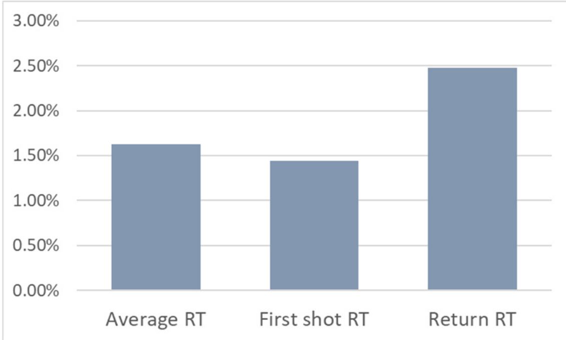

Figure 8: Percentage difference in various game situations between players with ATP rankings between #130 to #400 and between #400 to #1066.

4 CONCLUSIONS

In this paper, 2D video analysis was successfully applied to assess RTs in tennis matches. RTs of high-level tennis players have been shown to be very short, sometimes less than 120 ms, especially in defensive actions, when the player often starts before the opponent's attacking shot. This result prompts us to consider the importance of perceptual kinetic skills, such as reaction speed and anticipation, in tennis training. No relevant correlations were found between reaction time and ranking. It would be interesting to enlarge the sample and involve elite top10 players in future works. Further development of this study may focus on techniques for training perceptual skills in tennis players with measurement of the possible improvement of RTs in matches, investigating also the effectiveness of different types of first movement. Another possibility of new work advancements could involve 3D video capture using binocular cameras (Zanela et al., 2022) and analysis techniques based on artificial intelligence (Vincenzo Bonaiuto et al., 2023).

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