Validating and Identifying KPIs in ATP/WTA hard court tennis match play (2019-2023) using the PWOL method.

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Abstract

The study provided further validity for the use of the PWOL (percentage of matches which the winner outscored the loser) method within elite hard-court tennis. Over half of the ATP/WTA competitive calendar (January-March and August-November) is played on hard courts so is an important progression. Data from 810 men's and 586 women's hard court matches across Grand Slams and ATP/WTA World Tours (i.e., Masters, 500s and 250s) between 2019 and 2023 was used for analysis. PWOL was validated alongside two traditionally used statistical methods (paired t-test, point-biserial correlation). Very high agreement between all approaches was shown using Spearman's correlation analysis for both men and women (> 0.97). The study further identified the indicators most related to winning performance, identifying baseline points won, first serve points won, points won of 0-4 rally length and Winners:UE Ratio to be most strongly associated with success; while forced errors were most associated with losing. Ball three indicators lacked association with match outcome, suggesting any major focus training 'one-two punches' on serve should be approached with caution. PWOL has proven to be a valid method for assessing success in elite hard-court tennis (offering potential for wider sports application) to ultimately aid coach decision-making.

Keywords:

Racket sports, Performance analysis, Coaching process, Court surface, Elite tennis

Introduction

The understanding of key tactical contributors towards success is substantially limited in elite tennis.[1] A significant factor may be due to the lack of access to appropriate and detailed match play data. Hawk-Eye, who collate vast quantities of data across the ATP/WTA World Tour, have major control on the distribution, previously charging £150 to access a single match.[2] Despite a recent announcement on the release of ATP data for players, coaches, and analysts to freely use at no charge, it has not impacted the quantity one can access. Additionally, only matches relevant to the player or organisation can be accessed, meaning alternative methods are required for opposition analysis or large-scale tennis research.[2] One solution to this problem is the manual collection of match data through video analysis techniques (e.g., Dartfish, Sportscode). Whilst this source is not as rich (i.e., speed or angle of ball is not easily obtained), the process offers reliable information on overall player performance, thus still offering impact to the coaching process.[3-7]

Fitzpatrick et al.[8] created a new method, Percentage of matches in which the Winner Outscored the Loser (PWOL), to offer a simple and easily understood process to ascertain the metrics associated with success in clay court matches, before further establishing validity for grass court performance.[9] The method was compared to paired *t*-tests and point-biserial correlations, identifying excellent agreement. Fitzpatrick et al.[8,9] assessed commonly used performance characteristics from 2016 and 2017 Wimbledon and Roland Garros to understand how to be successful on grass and clay courts, identifying points won of 0-4 shot rally length, first serve points won and baseline points won to be most strongly associated with success on both surfaces for men and women. While the similarity between these two surfaces may be surprising given previous research identifying differences between surfaces[3,4,7,10-14], it must be understood that differences directly assessing match play characteristics may not directly translate to differences in the importance of these characteristics.

Research on surface type has been a common variable used to distinguish between performances[4,5,7,9-22], because of the surface on the trajectory of ball bounce, speed post-bounce, ball spin, and movement of the player.[11] Studies investigating surface differences identified rally length as being shorter at Wimbledon (grass) and longest at the French Open (clay[3]). With grass considered to be the fastest of the surfaces and clay the slowest, this leads to a potential difference in player demand throughout a match. A lower average rally length on a faster surface is likely a result of the increased effectiveness of the first serve, where grass and hard courts offer faster serve speeds resulting in less time for the serve-returner to react.[22] This also affects the ability to break serve, with returners having a significantly greater opportunity to break on clay than on grass.[10] Hence, further analysis combining contextual variables (player quality, sex, winner's vs loser's) with match performance metrics offers the potential to identify differences between scenarios with the aim of implementing such knowledge in their own game to achieve success.

When comparing winning and losing players, findings revealed that winners perform better overall, independent of the surface, coming out superior in serving, returning, and rally parameters.[8,9,12,15,21,23] A similar pattern is found in the comparison of sex, with male players performing to a better standard across all performance indicators on each surface from 2003 to 2017.[4,8,9,11,19,24] The assessment of player quality (i.e., ranking) with surface type has the potential to provide useful information on how players of varied quality could potentially play against one another to achieve successful match outcome on different surfaces. Nine studies focused on this relationship.[14,16-21,23] Results contradict somewhat with Sánchez-Pay et al.[13] highlighting no correlation between ranking and first/second serve won % on hard court, whereas Söğüt[14] discovered the inverse. Söğüt[14] also identified differences between surfaces; for example, no relationship was highlighted between ranking and serve-return on hard courts,

97 yet significant correlations between first serve-return won % on clay and second serve-return
98 won % on grass were found.

99 Previous research on hard court performance has often sought to analyse performance
100 across a variety of contextual variables.[20] However, success has been measured by win % and
101 differences between performers measured directly by statistical tests. PWOL could offer a more
102 user-friendly alternative understood by coaches and players in a practical environment and is
103 already proven to be a valid measure of success within clay and grass court match play.[8,9] Much
104 of the ATP/WTA World Tour season (January-March and August-November) is played on
105 hard courts, thus performances on this surface are essential towards long-term ranking
106 development. Replicating the statistical methods used by Fitzpatrick et al.[8] for the remaining
107 surface-type (i.e., hard court) is warranted by virtue of the surface speed variations[11,21,24] which
108 may lead to different aspects of match play highlighted as more important to successful
109 outcome. Consequently, establishing the performance characteristics associated with success
110 on hard-court could ensure, in combination with Fitzpatrick et al.[8-9], that the inter-seasonal
111 differences (hard, clay, grass court variations) are considered during training periodisation,
112 ultimately enhancing in-season preparation.

113 Due to a lack of large-scale research for hard court match play; a method not
114 specifically validated for use on hard court surfaces[8]; and the common use of solely Grand
115 Slam datasets, a significant and impactful gap for applied practice remains unanswered.
116 Specifically, a large-scale study identifying key performance indicators (KPIs) that associate
117 most with success, using the PWOL method, across Grand Slams and all World Tour levels
118 (ATP/WTA 1000's, 500's, and 250's) on hard courts appears to be a logical progression within
119 enhancing our knowledge of the game. An additional aim of this study will be to strengthen
120 the validity of the PWOL method for hard-court match play by assessing its agreement with

two commonly used statistical methods as used by Fitzpatrick et al.[8]; 1) point-biserial correlations and 2) paired *t*-tests respectively.

Methods

Sample

With permission from a national tennis organisation, 810 men's and 586 women's hard court matches across Grand Slams and all levels (i.e., Masters, 500s and 250s) of the ATP and WTA World Tours from 2019 to 2023 were used for analysis. Data were collected via a bespoke tagging panel in Dartfish Live S (Dartfish, Switzerland) by a cohort of specially trained tennis analysts working for the organisation – all with three or more years of experience as tennis analysts - or an external company in partnership with the organisation. External analysts receive extensive training until the quality of the data collection satisfies the standards of the national tennis organisation. Once video recordings of the matches are tagged, the collated data was exported into a .csv format and funnelled through an automatic error checker, ensuring no data is missing or tagged incorrectly. Ethical approval was gained Middlesex University's London Sports Institute Ethics Committee [ETH25715].

Performance Indicators Collated

In a similar manner to Fitzpatrick et al.[8], the following performance indicators were collected for the winner and loser in each match: aces, double faults, first/second serve quality, first/second serve points won, first/second serve-return points won, first/second serve-return effectiveness, ball three - also known as "Serve Plus One", defined as the second shot the server hits in a rally following the serve-return - forehand, ball three attacking/neutral/defensive, baseline points won, net points won, drop shot points won, break points won, winners/unforced/forced errors, and points won of rally lengths 0-4, 5-8, and 9+ shots. The

three situations (i.e., attacking, neutral and defensive) are based on the location, speed and trajectory of the ball received, the area of the court the ball is hit, and the time the player has available to hit the shot. Using the equations set out in Table 1, data was subsequently normalised as a percentage in relation to overall match performance akin to Fitzpatrick et al.[8].

Table 1 – Equations used to generate normalised performance indicator data in relation to overall match performance.

Performance indicator	Equation
Aces (%)	Number of aces/number of serves (x100)
Double faults (%)	Number of double faults/number of points served (x100)
First serve quality (%)	(Number of first serves in/number of first serves hit) * (Number of effective first serves (ace, unreturnable serve, attacking ball three)/number of first serve points played) (x100)
First serve points won (%)	Number of first serve points won/number of first serve points played (x100)
Second serve quality (%)	(Number of second serves in/number of second serves hit) * (Number of effective second serves (ace, unreturnable serve, attacking ball three)/number of second serve points played) (x100)
Second serve points won (%)	Number of second serve points won/number of second serve points played (x100)
First serve-return points won (%)	Number of first serve-return points won/number of first serve-return points played (x100)
First serve-return effectiveness (%)	Number of effective first serve-returns (return winner, neutral/defensive ball three)/number of first serve-return points played (x100)
Second serve-return points won (%)	Number of second serve-return points won/number of second serve-return points played (x100)
Second serve-return effectiveness (%)	Number of effective second serve-returns (return winner, neutral/defensive ball three)/number of second serve-return points played (x100)
Break points won (%)	Number of break points won as returner/number of break points played as returner (x100)
B3 FH (%)	Number of ball three shots hit with a forehand/number of rally points played (x100)
B3 Attacking, Neutral or Defensive (%)	Number of ball three shots hit in an attacking [or neutral, or defensive] situation/number of rally points played (x100)
Baseline points won (%)	Number of baseline points won/number of baseline points played (x100)
Net points won (%)	Number of net points won/number of net points played (x100)
Winners:UE Ratio (%)	Number of winners:number of unforced errors (x100)
Forced errors (%)	Number of forced errors/number of rally points played (x100)
Points won of 0-4 rally length (%)	Number of points won of 0-4 rally length/number of points played of 0-4 rally length (x100)
Points won of 5-8 rally length (%)	Number of points won of 5-8 rally length /number of points played of 5-8 rally length (x100)
Points won of 9+ rally length (%)	Number of points won of 9+ rally length /number of points played of 9+ rally length (x100)

Reliability Testing

Inter-rater variability can occur due to the subjective nature of the tagging process, hence inter-rater reliability testing was used to establish the agreement between the lead researcher and the other taggers involved. As performed by Fitzpatrick et al.[9], the lead researcher re-tagged eight matches using Dartfish (Live S) in conjunction with the same custom tagging panel. Inter-rater reliability was then assessed using Cohen's kappa coefficient.[25] Cohen's kappa coefficient was $\kappa = 0.94$ demonstrating 'Excellent' agreement.

PWOL Method and Statistical Analyses

Percentage of matches which the winner outscored the loser (PWOL) is a method that compares the performance of the winning and losing player for each performance indicator to identify which player outperformed the other on a match-by-match basis. A percentage is calculated by dividing the number of matches the winner outscored the loser by the overall number of matches. A PWOL of 50% for a performance indicator has no association with success, whereas an increase towards 100% indicates a strong association with success (or winning), while any decrease towards 0% indicates a stronger association with failure (or losing). For example, if the winner has a first serve points won % greater than the loser in 150 out of 200 matches, the PWOL for this indicator would be 75%. This process was undertaken for male and female players separately, with the prevalence of each performance indicator for winners and losers presented as mean ± SD where appropriate.

The results from the PWOL method were compared to traditional statistical tests to reinforce validity. Data were imported into SPSS (v28.0, SPSS Inc., USA). Point-biserial correlations (r_{pb}) were used between match outcome and performance indicator to ascertain association with match outcome.[26-27] A paired *t*-test comparing winners and losers was completed where the t values were used to distinguish between the two groups.[27-28] The greater

the *t* value, the more associated with an outcome it is (i.e. positive for winning, negative for losing), while a value close to zero suggests no association to match outcome. The results of each method were used to illustrate relative importance of each indicator. To assess agreement between the results of the methods (i.e., establish the validity of the PWOL method for hard court surfaces) pairwise comparisons between PWOL values, t values and point-biserial correlation coefficients were performed using Spearman's rank-order correlation coefficients, akin to Fitzpatrick et al.[8].

Results

Table 2 shows the mean and standard deviation of all performance indicators for winning and losing players, for men. Each of the statistical methods identified baseline points won, first serve points won, points won of 0-4 rally length and Winners:UE Ratio as the most strongly associated with success amongst all performance indicators. In contrast, forced errors was most strongly associated with losing. Ball three performance indicators, such as ball three forehand, and ball three situational characteristics (i.e. attacking, neutral or defensive) were least associated with match outcome, alongside double faults.

Table 2. Men's indicators (presented as mean ± sd), point-biserial correlations with match outcome, t values and PWOL values; sorted by r_{pb}

Performance Indicator	Winning players	Losing players	r_{pb}	t	PWOL
Baseline points won (%)	54.8 ± 4.6%	45.1 ± 4.6%	0.73	30.17	89.1%
First serve-return points won (%)$^{+}$	31.9 ± 8.6%	23.0 ± 7.4%	0.49	24.49	81.6%
Points won of 0-4 rally length serving (%)	76.8 ± 7.1%	68.3 ± 8.3%	0.49	24.47	82.2%
Points won of 0-4 rally length returning (%)	31.7 ± 8.3%	23.2 ± 7.1%	0.49	24.44	82.1%
First serve points won (%)$^{+}$	77.0 ± 7.4%	68.0 ± 8.9%	0.48	24.17	81.6%
Second serve points won (%)$^{+}$	54.5 ± 10.1%	45.5 ± 10.3%	0.40	17.86	72.9%
Second serve-return points won (%)$^{+}$	54.4 ± 10.3%	45.4 ± 10.1%	0.40	17.88	72.9%
Winners:UE Ratio (%)	89.1 ± 44.3%	59.8 ± 29.6%	0.36	17.56	76.6%
Points won of 5-8 rally length serving (%)	56.7 ± 12.7%	47.7 ± 12.8%	0.33	13.87	67.8%
Points won of 5-8 rally length returning (%)	52.3 ± 12.8%	43.3 ± 12.7%	0.33	13.88	67.8%
Break points won (%)	48.3 ± 20.7%	31.7 ± 28.9%	0.31	13.53	73.2%
Points won of 9+ rally length serving (%)	53.5 ± 19.2%	42.1 ± 17.1%	0.30	12.40	69.2%
Points won of 9+ rally length returning (%)	56.7 ± 17.6%	45.6 ± 19.0%	0.29	12.23	69.0%
First serve quality (%)	39.0 ± 8.9%	34.3 ± 8.4%	0.26	11.60	66.4%
Net points won (%)	69.3 ± 14.9%	62.2 ± 15.7%	0.22	9.04	63.0%
Aces (%)	9.9 ± 6.5%	7.4 ± 5.0%	0.21	8.36	61.5%
First serve-return effectiveness (%)	43.3 ± 13.1%	38.3 ± 13.0%	0.19	8.09	63.0%
Second serve quality (%)	23.2 ± 10.9%	20.3 ± 9.8%	0.14	6.36	59.0%
Second serve-return effectiveness (%)	77.1 ± 11.6%	74.3 ± 12.3%	0.12	5.30	57.5%
B3 Attacking (%)	25.3 ± 11.2%	23.9 ± 10.7%	0.07	2.83	54.0%
B3 Neutral (%)	65.4 ± 12.0%	66.9 ± 11.9%	0.06	-2.92	44.6%
B3 FH (%)	65.3 ± 12.5%	64.5 ± 12.2%	0.03	1.34	53.0%
B3 Defensive (%)	9.3 ± 6.7%	9.2 ± 6.5%	0.003	0.14	47.8%
Double faults (%)	3.3 ± 2.4%	4.1 ± 2.9%	-0.14	-5.89	43.1%
Forced errors (%)	9.8 ± 4.1%	11.1 ± 4.3%	-0.15	-6.91	39.4%

Note:$^{+}$ Identical PWOL as serve return point won% = 100 – opponent's serve points won%.

Table 3 shows the mean and standard deviation of all performance indicators for winning and losing players, for women. Each of the statistical methods identified baseline points won, first serve points won, points won of 0-4 rally length and Winners:UE Ratio as the most strongly associated with success amongst all performance indicators. In contrast, forced errors is most strongly associated with losing. Ball three performance indicators were least associated with match outcome, alongside double faults. Compared to men, points won of 5-8 rally length are more associated with winning (PWOL = 67.8% for men, 73.9% for women), whilst break points won are less important (PWOL = 73.2% for men, 68.8% for women).

Table 3. Women's indicators (presented as mean ± sd), point-biserial correlations with match outcome, t values and PWOL values; sorted by r_{pb}

Performance indicator	Winning players	Losing players	r_{pb}	t	PWOL
Baseline points won (%)	55.7 ± 4.7%	44.3 ± 4.6%	0.78	29.70	90.9%
First serve-return points won (%)$^{+}$	40.9 ± 9.4%	29.6 ± 8.8%	0.53	23.13	83.7%
First serve points won (%)$^{+}$	70.4 ± 8.8%	59.1 ± 9.4%	0.53	23.14	83.7%
Points won of 0-4 rally length serving (%)	68.5 ± 8.7%	57.9 ± 9.7%	0.50	21.09	81.5%
Points won of 0-4 rally length returning (%)	42.0 ± 9.7%	31.5 ± 8.7%	0.50	21.05	81.5%
Second serve points won (%)$^{+}$	50.9 ± 10.5%	40.1 ± 10.3%	0.46	17.49	75.5%
Second serve-return points won (%)$^{+}$	59.9 ± 10.3%	49.1 ± 10.6%	0.46	17.47	75.3%
Winners:UE Ratio (%)	82.6 ± 40.9%	50.3 ± 22.7%	0.44	18.05	79.9%
Points won of 5-8 rally length returning (%)	56.7 ± 11.7%	45.3 ± 12.3%	0.43	15.91	73.9%
Points won of 5-8 rally length serving (%)	54.7 ± 12.3%	43.3 ± 11.7%	0.43	15.88	73.9%
Break points won (%)	53.8 ± 18.3%	39.6 ± 24.9%	0.31	10.93	68.8%
First serve quality (%)	29.1 ± 8.8%	24.2 ± 7.8%	0.28	11.28	68.0%
First serve-return effectiveness (%)	60.1 ± 13.6%	52.4 ± 14.5%	0.26	10.48	66.3%
Points won of 9+ rally length returning (%)	58.0 ± 19.8%	47.5 ± 22.5%	0.24	8.06	65.8%
Points won of 9+ rally length serving (%)	51.3 ± 22.6%	41.2 ± 19.5%	0.23	8.00	65.5%
Aces (%)	5.2 ± 4.4%	3.4 ± 3.4%	0.23	8.56	64.8%
Net points won (%)	69.6 ± 18.9%	61.4 ± 18.3%	0.22	7.41	64.6%
Second serve quality (%)	20.7 ± 9.5%	16.6 ± 8.5%	0.22	8.40	62.2%
Second serve-return effectiveness (%)	80.3 ± 10.2%	76.2 ± 11.0%	0.19	7.10	61.4%
B3 Attacking (%)	16.8 ± 9.8%	14.2 ± 8.8%	0.14	4.86	57.0%
B3 FH (%)	56.8 ± 11.7%	55.3 ± 11.1%	0.07	2.47	52.7%
B3 Defensive (%)	12.1 ± 7.9%	12.4 ± 8.1%	-0.02	-0.62	48.5%
B3 Neutral (%)	71.0 ± 10.6%	73.3 ± 10.4%	-0.11	-4.88	42.1%
Double faults (%)	4.7 ± 3.3%	5.8 ± 3.7%	-0.16	-5.60	42.0%
Forced errors (%)	8.4 ± 3.6%	9.9 ± 4.2%	-0.19	-6.60	39.5%

Note:$^{+}$Identical PWOL as serve return point won% = 100 – opponent's serve points won%.

Agreement between methods

All Spearman's rank-order correlation coefficients demonstrated excellent agreement between each of the methods[29], with all values above 0.97. Overall, correlations were slightly stronger for women compared to men.

Table 4. Spearman's rank-order correlation coefficients for each pairwise comparison

Pairwise comparison	Men	Women
r_{pb} and t	1	0.99
r_{pb} and PWOL	0.97	1
t and PWOL	0.98	0.99

Note: All correlations were significant at p <.001.

Discussion

The aim of this study was to provide further validation for the PWOL method[8] in respect of hard-court performance. Following an identical procedure to Fitzpatrick et al.[8], this study compared traditional statistical methods; point-biserial correlations and paired *t*-tests with the PWOL method. Spearman's rank-order correlations demonstrated excellent agreement between the three methods (r between 0.97 and 1.00; $p < 0.001$), for both the men's and women's analysis. This finding supports Fitzpatrick et al.[8] within elite clay court match play (rs 0.94-0.98) and further validates the use of the PWOL method. It was vitally important to confirm validity considering; the use of a considerably larger dataset, additional tournament levels (i.e., not only Grand Slams), and most importantly the use of a different surface being played on (i.e., hard court). Highlighting PWOL to be valid for hard court match play reaffirms the versatility of the method across the sport and, if harnessed appropriately, offers vast potential for practical use within the performance analysis field across a multitude of sports. Specifically, PWOL can identify performance indicators associated with success as effectively

as more complex statistical methods with a much simpler approach. Hence, elite coaches should consider using PWOL to make well-informed, objective decisions for training and tactical match preparation.

A second aim was to identify KPIs on hard courts in comparison to those highlighted as important on clay and grass court surfaces.[9] Analysis identified the same performance indicators exhibited the highest PWOLs compared to other surfaces, including baseline points won, first serve points won, and points won of 0-4 rally length. The Winner/UE Ratio was found to have the next highest PWOL and association with success, although the two statistical methods disagreed marginally. At the other end, forced errors and double faults similarly exhibited the lowest PWOL values, highlighting their strong association with losing on all surfaces. Comparing the three surfaces, some key differences can be found; however, comparisons must be approached cautiously considering the smaller sample size (2016 and 2017 Wimbledon and Roland Garros) used by Fitzpatrick et al.[9]. Another key factor is the difference between the prevalence and importance of performance indicators. A greater prevalence on one surface compared to another does not always mean greater importance on that surface, yet importance of a performance indicator is enhanced if more prevalent (i.e., high/low PWOL + high prevalence = extreme importance).

Performance Indicators Associated with Winning

O'Donoghue and Ingram[30] found women to have significantly more ($p < 0.001$) baseline rallies than men across all Grand Slam events. Despite baseline points won having the strongest association with winning for both sexes, the additional prevalence for women suggests it may be a more important indicator within women's tennis. Notably however, men's tennis has seen a drastic change from serve and volley tactics towards a more prominent baseline game over the last few decades.[31] To support this notion, PWOL is greater for women than men on all

surfaces for baseline points won; however, it is perhaps unexpected that clay does not have the greatest PWOL between each surface. For men and women, PWOL is higher on hard courts than clay, with grass courts also higher for women.[9] A possible explanation could be that a higher prevalence of baseline rallies on clay courts, due to the slower ball speed off the surface, resulting in more time to retrieve each shot[30] increases the chances of parity in points won (i.e., 50/50 split) as the advantage of serving decreases exponentially the longer a point continues.[32]

Almost half (46.3%) of short points (i.e. 0-4 rally length) are 1 shot in rally length in the men's game, over a third (36.3%) for women, with points of 2 shot rally length most associated with success[33], highlighting the importance of the serve and serve-return. These KPIs are highly associated with winning across all surfaces for both sexes, with very little variation in PWOL between the three surfaces. However, a limitation of PWOL becomes present, whereby variations in stature[34], handedness[20], tournament level[5], and ball wear[4], which affect serve and serve-return performance, are overlooked. This may explain why serve equality and serve-return effectiveness have lower association with match outcome. Although unpublished, Venn[35] provided further context to the serve-return strategy highlighting that winning players hit more to external areas of the court while hitting central was most associated with losing.

As on grass and clay courts, points won of 0-4 rally length on hard courts were most associated with success compared to all other rally length performance indicators. However, the scale of this association is much weaker for men, with a PWOL around 10% lower than on grass and 7% lower than clay. Rallies are generally longest on clay and shortest on grass courts[30], so a PWOL lower on hard compared to clay is particularly surprising. This could be due to definitional differences for rally shot count; for example, if a rally ended in an error on the 5th shot, it would be placed into the 5-8 rally length category here; but may be classed as 0-4 in rally length for Fitzpatrick et al.[9] if the final shot is discounted due to the error.

Winners:UE Ratio was used to combine two performance indicators and validate a common phrase used by tennis practitioners who suggest hitting more winners than unforced errors in a match associates strongly with success.[33] Results support this, identifying a strong association with winning. However, even for winning players, hitting more winners than unforced errors were not attainable on average (89.1 ± 44.3 for men, 82.6 ± 40.9% for women). Therefore, instead of requesting a player hits more winners the analysis can provide a benchmark to aim for (ratio of 9:10 for men and 4:5 for women) as a more realistic goal. Depending on playing style, this offers an aggressive baseliner/serve and volleyer the freedom to keep attacking, or a defensive counterpuncher the knowledge that unforced errors are acceptable as long as a good ratio is met.

Performance Indicators Associated with Losing

Forced errors was the only performance indicator strongly associated with losing (i.e., PWOL < 40%)[8] for both sexes. This largely follows expectations, considering it results in losing the point directly. On grass and clay, forced errors were considerably more important (i.e., more associated with losing) for men than women – mostly attributed to game style differences, where men are naturally more powerful in general than women, resulting in more tactical variety and more forced errors.[8] On hard courts, the forced error has a similar association with losing for both sexes (Men = 39.4%, Women = 39.5%); however, this largely stems from the variation in the men's game between surfaces. Hard courts attained a PWOL 12% and 17% higher than grass and clay, respectively, while minimal variation is evident for women between surfaces. Forced errors tend to be very subjectively judged often requiring a contextual evaluation of situation in relation to court type characteristics (e.g., player court position, speed and bounce height of ball received, opposition court position, among others); hence, some disparity of results can be understood between studies although such a large difference is

surprising.

Performance Indicators Least Associated with Match Outcome

All Ball Three indicators (B3 Attacking, B3 Neutral, B3 Defensive and B3 FH) exhibited PWOLs between 44.6% and 54.0% for men and 42.1 and 57.0% for women, highlighting the anecdotal importance placed on 'serve plus one' may be misguided, as also found by.[33] The consensus of being in an attacking situation on ball three more often would contribute significantly towards winning matches, and vice versa for defensive situations, was disproved by the PWOLs suggesting a lack of importance. Similarly, the forehand is commonly favoured over the backhand as the stronger shot and hitting more forehands on ball three would logically be advantageous, but this is disproven.

With points won of 0-4 rally length strongly associated with success on all surfaces, Fitzpatrick et al.[9] suggested that serve and/or serve-return quality determined the outcome of a large proportion of points. However, serve quality and serve-return effectiveness are shown to have a minimal impact on winning for both sexes. Winning or high quality players have previously been proven to outperform losing or lower quality players in all serve parameters on all surfaces[12-14,16-19,21,31,36-39]; therefore, results further validate the idea that higher prevalence does not always mean greater importance.

Previous research has found players of higher quality serve significantly fewer double faults and more aces than lower-quality players.[16,17,19,37] For men, PWOLs suggest serving is most important on grass, which is unsurprising considering the greater surface speeds.[11] However, for women, aces have a hard court PWOL 8% higher than grass and clay. Mecheri et al.[11] found equal efficiency between flat, high velocity serves and high spin intensity, slower velocity serves. More research is required in this area, but it may be that women are able to use

high spin intensity serves to greater effect on hard courts than any other surface, with winning players utilising this more.

With rally length longer on hard courts, it was expected for points won of 9+ shots to be more associated with winning than on grass, but for women, a PWOL 10% higher than clay was identified. Net points won has a small association with winning, potentially due to the lack of prevalence of professional tennis while baseline points won has the strongest association, further accentuating the move towards a baseline game style in recent times. Previous research identified winners performed better than losers on break points[39-40], and results strongly agreed, with winners winning a greater percentage of break points (Men = 48.3%, Women = 53.8%) than losers (Men = 31.7%, Women = 39.6%). This results in relatively strong associations with success across all surfaces, although lower for women due to a greater likelihood of breaking and being broken, with increased time to react and hit more effective returns by virtue of slower serve speeds.

Future Directions and Conclusion

Baseline points won, first serve points won, points won of 0-4 rally lengths, and Winners:UE Ratio had the strongest associations with winning for both sexes in elite hard court match play, with forced errors most associated with losing. Like grass and clay[9], players should focus on baseline play, short points, and point-ending strategies during training, using the high prevalence of baseline rallies and short points in the current game to their advantage. Any emphasis on ball three should be carefully approached as it appears to have limited effect on the match outcome. Whilst winning points on serve is greatly important, aces, serve quality, and double faults lack importance, suggesting players should take a match-by-match approach focusing on tactical planning in relation to opposition strengths and weaknesses.

With hard court tournaments played from January to March and August to November through a normal ATP and WTA calendar year, encapsulating 2/4 major Grand Slams, 6/9 ATP 1000 events, and 7/10 WTA 1000 events, an analysis of elite match-play highlighting KPIs on the surface was warranted. The transfer of game style across the three surfaces does not need to drastically change, apart from a slightly greater emphasis on 1) baseline points for both sexes on hard court and 2) serving for men on grass court. Although separated comparisons between surfaces do provide useful insight, a much larger-scale analysis using PWOL across the same calendar period, utilising identical indicators and associated definitions, is required for grass and clay to ensure cross-comparison validity. Consequently, PWOL could be used to delve into contextual variables such as handedness, tournament level, pressure points, and stature. PWOL has vast possibilities within tennis (and potentially wider sports application) with doubles and wheelchair tennis yet to be explored, ultimately aiming to aid decision-making regarding training and competitive strategies.

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