Accepted Manuscript

Title: Heat stress incident prevalence and tennis matchplay performance at the Australian Open

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PII: S1440-2440(17)31024-1
DOI: http://dx.doi.org/10.1016/j.jsams.2017.08.019
Reference: JSAMS 1609

To appear in: *Journal of Science and Medicine in Sport*

Received date: 12-5-2017
Revised date: 24-8-2017
Accepted date: 29-8-2017

Please cite this article as: Smith Matthew T, Reid Machar, Kovalchik Stephanie, Woods Tim O, Duffield Rob.Heat stress incident prevalence and tennis matchplay performance at the Australian Open.*Journal of Science and Medicine in Sport* http://dx.doi.org/10.1016/j.jsams.2017.08.019

Full title: Heat stress incident prevalence and tennis matchplay performance at the Australian Open.

Running Title: Professional men's tennis in the heat.

Paper type: Original investigation

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Abstract word count: 238

Text only word count: 3130

Number of tables: 3
Number of supplementary tables: 2
Number of figures: 0

ABSTRACT

Objective: To examine the association of wet bulb globe temperature (WBGT) with the occurrence of heat-related incidents and changes in behavioural and matchplay characteristics in men's Grand Slam tennis.

Methods: On-court calls for trainers, doctors, cooling devices and water, post-match medical consults and matchplay characteristic data were collected from 360 Australian Open matches (first 4 rounds 2014-16). Data were referenced against estimated WBGT and categorised into standard zones. Generalized linear models assessed the association of WBGT zone on heat-related medical incidences and matchplay variables.

Results: On-court calls for doctor (47% increase per zone, p=0.001), heat-related events (41%, p= 0.019), cooling devices (53%, p<0.001), and post-match heat-related consults (87%, p=0.014) increased with each rise in estimated WBGT zone. In WBGT's >32ºC and >28ºC, significant increases in heat-related calls (p=0.019) and calls for cooling devices (p<0.001), respectively, were evident. The number of winners (-2.5±0.006% per zone, p<0.001) and net approaches (-7.1±0.008%, p<0.001) reduced as the estimated WBGT zone increased, while return points won increased (1.50± 0.459, p<0.001). When matches were adjusted for player quality of the opponent (Elo rating), the number of aces (5±0.018%, p=0.003) increased with estimated WBGT zone, whilst net approaches decreased (7.6±0.013%,p<0.001).

Conclusions: Increased estimated WBGT increased total match doctor and trainer consults for heat related-incidents, post-match heat-related consults (>32ºC) and cooling device callouts (>28ºC). However, few matchplay characteristics were noticeably affected, with only reduced net approaches and increased aces evident in higher estimated WBGT environments.

Keywords: heat illness, court sports, matchplay

INTRODUCTION

The Australian Open (AO), one of the four Grand Slam tennis tournaments, is held during the Australian summer with matchplay regularly occurring in high (>28ºC) and sometimes extreme (>32ºC) wet bulb globe temperatures (WBGT). In such conditions the risk of heat illness [1-3] and reduced performance [4, 5] is of concern; though evidence from professional tennis matchplay remain scarce [6]. The protection of players, officials and spectators necessitates the existence and implementation of extreme heat policies, which guide continuation or suspension of play. The current AO policy is guided by the WBGT index, which is widely deployed [7-9] as a measurement of environmental conditions for human comfort [10]. Indeed, it is instructive that the American College of Sports Medicine (ACSM) has used the WBGT to derive general guidelines for exercise in the heat. For example, exercising strenuously in conditions >28ºC (WBGT) is considered “high risk” while exercise is suggested to be stopped >32ºC [3, 11]. However, such conditions are regularly encountered at the AO, and much debate exists regarding the fair implementation of the extreme heat policy to ensure player wellbeing without compromising the tournament's integrity.

Strenuous exercise in hot environmental conditions increases the potential for developing heat illnesses [1, 12] such as, heat cramps, heat exhaustion and heat stroke [3, 12]. Limited literature of heat illness exists in professional tennis, though the US Open (between 1994 and 2009) has previously documented heat illness occurrence rates of 2.84 per 1000-match exposures in men’s matches [13]; despite the recorded environmental conditions appearing too temperate (26-33ºC ambient temperature) to pose a high risk [13]. Regardless, these data confirm the presence of heat illness in tennis, yet provide little insight into player discomfort. Accordingly, a focus on other indicators of player distress, such as calling for additional water or cooling devices, would help to further clarify the level of environmental stress experienced *insitu* by professional tennis players.

In the absence of specific heat stress data measurement of core temperature responses to matchplay in the heat are used as evidence of the inferred risks [6, 14]. During matchplay in a range of ambient temperatures (14.5 - 38.4ºC dry bulb) core temperatures remain within normal exercise-induced physiological ranges (37.0 to 39.0ºC), though core temperatures can reach ~39.5ºC [15, 16]. Evidence of changes in tennis performance due to increased temperature are largely anecdotal, suggesting reductions in ball velocity and court movement speed. However, repeated-sprint, change of direction and vertical jump following matchplay in hot temperatures appear unaffected when compared to cooler temperatures [14]. Further, the number of games, points, aces, double faults, or the length of points have also been shown to be unaffected between hot and cool playing conditions [17]. In part, the maintenance of normal core temperatures and lack of reduction in physical capacities may be attributed to modifications in on-court behavior, such as increased between-point rest duration to manipulate work-to-rest ratios [17]. However, these studies are not representative of the cohort or performance context of Grand Slam competitions, with participants in these studies having much lower professional rankings than most Grand Slam competitors.

The risk of heat illness and reduction in performance during Grand Slam matchplay remains relatively poorly understood and the effect of extreme heat on player wellbeing and performance is speculative. Accordingly, to determine the effect of environmental conditions on Grand Slam tennis, this study retrospectively examined the association between estimated WBGT and markers of heat-related trainer and doctor consults, behavioral responses and match characteristics at the men's Australian Open. It was hypothesized that increased estimated WBGT would result in increased heat-related trainer/doctor consults and alter player behavior (i.e. calls for water and cooling devices) with minimal changes to match characteristics.

METHODS

Data were obtained from all 360 matches in the first four rounds of the 2014, 2015 and 2016 AO Men's Main Draw, made up of 189 participants with a mean ± standard deviation (SD) age of 27.8±3.8 years, from 54 countries and an Association of Tennis Professionals rank of 66±69. Consent for the use of data for research purposes was gathered from all participants upon entry to the tournament via tournament conditions of entry. This study was approved by the University of Technology Sydney Human Research Ethics Committee (UTS REF: 2015000126).

Descriptive point level data and player rank information were collected from the AO tournament organisers. Point level data were generated in real time via match umpires and/or tennis match coding professionals. These coding professionals were extensively trained and used a platform that is widely deployed. While no reliability data is available on the coding professionals, tennis match statistics have been shown to have very high levels of inter- and intra-tester reliability [18]. Point level data of all match characteristics outlined in Supplementary Table 1 were collected and aggregated to the match level. Match averaged estimated WBGT was calculated from weather data retrospectively collated from half-hourly recordings from an Australian Bureau of Meteorology weather station located within 100m of the venue. Due to the Australian Bureau of Meteorology not explicitly measuring globe temperature, an estimated WBGT is provided instead to categorise matches based on: WBGT = 0.567 x Ta + 0.393 x e + 3.94, where Ta= dry bulb temperature (ºC) and e = Water vapour pressure (hPa) [humidity]. This formula is recommended by the ACSM for estimating WBGT without black globe temperature [2, 19], and has been successfully used in large scale meta-analysis of physical performance in hot environments [20], and in studies where black globe temperature was not available [21]. Despite WBGT being one of several measures of thermal strain and its limitations related to potential underestimation of the stress of restricted evaporation[22], it is the primary measure of heat stress throughout international tennis [23, 24].

Time stamped tournament communication logs were used to inform the timing of on-court calls for medical consults and flagged as heat-related by presiding physician, alongside calls for cooling devices/water (see Supplementary Table 1 for further details). Post-match heat-related consults were collated from the AO medical database, which captures all athlete-doctor consultations during the event. Matches were excluded from analysis if they were missing data (ie., WBGT, on-court calls, or large amounts of match data) (n=22), suspended for rain or played under a closed roof (n=4). Matches that were suspended due to extreme heat policy were separated into pre- extreme heat policy and post-extreme heat policy and reintroduced into the data set as separate matches (n=3) and treated as individual matches in differing temperature zones. This was to ensure all data from matches in hotter conditions were included and to include all available performance data for players who had played in some of the hottest conditions. All data from court call logs, medical consults, match statistics and Australian Bureau of Meteorology recordings were collated into Microsoft Excel and classified into a WBGT zone according to the ASCM classification (1), zone 5: >32.3ºC, zone 4: 30.1-32.2ºC, zone 3: 27.9-30ºC, zone 2: 22.3-27.9ºC , zone 1: <22.2ºC (with ACSM's zones <10 and 10.1-22.2ºC being combined to form zone 1, and zones 22.3-25.6ºC and 25.7-27.8ºC being combined to form zone 2).

Analyses for the present study were completed in RStudio version 0.99.902 (RStudio: Integrated Development for R. RStudio, Inc., Boston, MA). Generalised linear models (GLM) were used to assess zone associations study outcomes. Count outcomes were modelled with a Poisson distribution and continuous outcomes with a Gaussian distribution. Medical and behavioral outcomes were considered per match and per 1000 match hours. Odds ratios were calculated for medical call outs and behavioural characteristics in each WBGT zone. In these comparisons, zone 5 was the WBGT reference group and, being the reference group, we report the baseline odds of an event rather than the odds ratio. The odds for zone 5 were obtained by exponentiating the intercept term of the logistic model while the odds ratios were obtained by exponentiating the model coefficients corresponding to each comparison WBGT zone. Performance outcomes were assessed without adjustment for player quality ("unadjusted" models) and with adjustment for player quality ("adjusted" models). In the adjusted analyses, players were defined as being of *similar* quality if their pre-match Elo ratings, a metric that accurately captures a player's ability at the time of the match, were within 50 points of each other [25]. Elo ratings are based on the strength of their career wins rather than just ranking. The unadjusted analyses compared performance outcomes of all matches in each zone. Since by chance, these groups could have a different distribution of quality of players that could confound the assessment of the association with zone, the adjusted analyses matched each player and opponent in matches in the extreme zone group (5-3) to a match in a normal zone condition whose player and opponent were of similar quality (1-2). Confidence intervals are reported at the 95% level and statistical significance was defined as an effect of 5% significance or less.

RESULTS

With each increase in estimated WBGT zone there was an increase in total doctor calls (47% increase per zone; p=0.001), trainer calls for heat-related incidents (41%; p=0.019), post-match heat-related incident consults (87%; p=0.014), total heat-related incident consult (55%; p<0.001), and total calls for cooling devices (53%; p<0.001). When medical and behavioural events were examined as a rate per 1000 hours, the largest increases in total heat-related incidents and total trainer calls occurred from zone 4 to zone 5 (76.5% and 22.6% increases, respectively; Table 1). In contrast, non-heat related trainer calls decreased from zone 4 to 5 (58.9, 76.4 calls /1000h respectively), whilst zone 5 had the lowest rate of non-heat related trainer consults. Of note, the number of retirements significantly increased in zone 5 (29.44/1000h), with 2 of those retirements being heat incident related, whereas zone 4 had no heat-related retirements.

Table 2 summarises the odds ratio of medical and behavioural characteristics when compared to zone 5. The odds of a player calling for trainers during the match did not significantly change when each compared to zone 5 (p>0.05). For the odds of a doctor being called during a match, only zone 2 showed significant change with an 81% (p=0.032) decrease in likelihood when compared to zone 5; though zone 1 had no occurrences, and thus no comparison was made. The odds of a trainer/doctor call being a heat-related incident was only significantly different with zone 2, with a decrease compared to zone 5 (90%; p=0.004). Cooling device call outs decreased by 86% (p<0.001) in zone 2 when compared to zone 5, without significant differences to other zones (p>0.05). Non-heat related trainer/doctor on court calls, water call outs and post-match heat-related incident consults were statistically comparable between zones (p>0.05).

Supplementary Table 2 shows the match characteristics per estimated WBGT zone and their change without adjustment for player Elo quality. The number of points won on return of serve increased by 1.8±0.4 ($p<0.001$) points per increase in estimated WBGT zone, although the large standard error may make this result of modest practical significance. Further, both the number of winners (2.5±0.01%, $p<0.001$) and net approaches (7.1±0.008%, $p<0.001$) decreased for every increase in estimated WBGT zone. No other match characteristics showed significant differences between estimated WBGT zones ($p>0.05$).

Table 3 shows the match characteristics per estimated WBGT zone and change per zone when adjusted for differences in player Elo quality. Analysis suggests that aces increased by 5±0.018% ($p=0.003$) per increase in estimated WBGT zone, while net approaches decreased by 7.6±0.013% ($p<0.001$) per zone. No other match characteristics showed significant differences between estimated WBGT zones ($p>0.05$).

DISCUSSION

This study represents the first examination of the association of estimated WBGT and heat-related incidents, behavioural and matchplay characteristics in Grand Slam tennis. As expected, higher WBGT zones resulted in increased occurrence of heat-related incidents, which was particularly evident >32°C WBGT, and increased cooling device call outs >28°C WBGT. Regardless, there was minimal association between higher WBGT and most matchplay characteristics; with only net approaches and aces shown to decrease and increase in higher temperatures zones.

Although heat illness is caused by a number of factors, high environmental stress as represented by high WBGT, has been cast as a significant risk factor [2]. From the present study, it was demonstrated that estimated WBGT in professional men's Grand Slam tennis was positively related with heat-related incidence. More specifically, Grand Slam matchplay in conditions >32°C WBGT were characterised by the highest number of heat-related retirements (14.7/1000 h in zone 5) and ensuing post-match heat related medical consults (87%; $p=0.014$). Previously, the US Open reported heat-related incidence rates of 2.84 per 1000 match exposures, without association to environmental temperature, while the present study shows a significant association between estimated WBGT and heat related incidents with an in-match heat related incident rate of 14.71 per 1000 match exposures over the 3 year data set. Thus the current study highlights the extent of heat-related incidents relative to WBGT zone for Grand Slam tennis, these results generally align with the ACSM position stance [2] and the current AO heat policy [23], whereby matchplay can be suspended in temperatures above 32.5°C WBGT.

While the incidence of heat-related events increased >32°C WBGT, this study also demonstrated an increased number of calls for cooling devices, particularly from zone 2 to 3 (>28°C WBGT). Suggesting athletes began to find the conditions thermally challenging [26]. Surprisingly there was no significant increase in calls for water, although this may be due to high courtside availability of fluid. There are limited, if any, previous accounts of player behaviour during Grand Slam matchplay in the heat. Consequently, this paper provides initial evidence that player discomfort becomes evident in temperatures beyond 28°C WBGT, although it must be noted that our use of WBGT zones precludes the determination of an explicit inflection point for increased player discomfort.

In the present study neither mean match duration nor total number of points per match differed with increased estimated WBGT zones. This finding contrasts with previous research, in lower ranked professional tennis players, which suggests match duration increases in the heat because of increased rest periods [17]. It is important to note that previous research was conducted on timed simulated matchplay, possibly reducing participant's motivation given career success was not determined by match outcome. The similarity in match duration between estimated WBGT zones in the current study may also relate to the ITF ruling that a maximum of 20 sec is allowed between points in professional tennis, thus preventing manipulation of rest period durations [9] or a decrease in point duration. However, it cannot be discounted that the increase in trainer/Doctor call outs with increasing estimated WBGT zone may indicate an attempt by players to slow the match down to reduce effective play percentage by using a medical time out [9].

The impact of extreme heat on tennis matchplay characteristics is relatively unknown, with suggestions of negligible influence on number of games, points, aces, double faults, or the point duration [17]. In the present study, most markers of matchplay did not significantly differ between estimated WBGT zones. However, an increase in return points won, decrease in the number of winners and the number of net approaches were evident as WBGT increased. It is important to note that the increase in return points won with each increase in estimated WBGT zone may be confounded by the high standard error, and the relatively small association. The 2.5% decrease in winners with each increase in estimated WBGT zone may relate to a decrease in the court coverage and a change of court position by players in hotter conditions, confounding their balance and ability to execute winners [27]. It may also be a case of winners or preceding shots to set up winners requiring more physical, technical or mental effort, meaning that a reduction in the number of attempted winners may also form a component of an overarching pacing strategy. Finally, the decrease in winners may have been explained by an increase in forced errors on the part of opponents; but, unfortunately, forced error data was not available to test this hypothesis. The significant decrease in the number of net approaches during hotter conditions (+7.1%, $p<0.001$) also infers that players adopted baseline oriented game styles to conserve energy and/or assume a more conservative approach to winning points [27].

The examination of match characteristics when match quality was statistically controlled revealed that the number of aces increased with each increase in estimated WBGT zone. Thus with increased WBGT, players seemingly attempted more decisive or riskier serves to shorten points and reduce the chances of extended matchplay, whereas during baseline rallies a more conservative approach is evident due to the decreased number of winners. Hence, players selectively choose when to be aggressive or conservative during matchplay in increased WBGT. Or, in other words, they're constantly evaluating risk and reward, where in this context the potential reward associated attempting to end the point quickly with the serve appears greater than that on offer when attempting to hit a groundstroke winner. This adoption of a more aggressive approach to serving appears to be further reflected in trend for an increase in the number of double faults as estimated WBGT zones increase (p=0.091). This may provide some preliminary evidence of tennis players adjusting their serve tactics to cope with increased WBGT's. Indeed, calls for players to adjust (the riskiness of) their serve strategy in accordance with the context of matches as well as their individual serving prowess is common in tennis [28]. As with the non-Elo adjusted matches, there was a significant decrease in the number of net approaches as temperatures increased. Again this implies that players altered their tactics to some extent, be that because of the physical exertion of net play, their reduced precision on approach or the perceived elevated risk associated with this tactic. With the lack of available data describing elite tennis in the heat, comparisons to other sports performed in the heat are instructive. For example, in various football codes players have been observed to cover reduced distances in high speed running zones under increasing WBGT [8]. While our data do not directly describe player movement, the noted decrease in net approaches and winners may be indicative of altered movement profile in tennis matchplay at the Grand Slam level.

Debate over the use of WBGT as a heat stress index [22] is common, yet still widely used in international tennis for determining implementation of extreme heat policy's [23, 24], and thus it is the most practically relevant for this study. That said, there are limitations of WBGT index related to equipment calibration and standardization [22] and lack of accounting for air movement or clothing within its calculation [29]. The current study also used estimated WBGT using moderate solar radiation with light wind, potentially underestimating "true" environmental stress [30]. While use of non-court side, estimated WBGT does reduce the accuracy of determining the true heat stress index, the wide ranging data set and use of zone-based analysis should reduce these limitations. Further, this study did not account for prior heat exposure on previous days; although Grand Slam formats result in limited singles matches on consecutive days.

Conclusion

In conclusion this was the first study to examine the association of estimated WBGT and heat-related incidents, behavioural and matchplay characteristics in men's professional Grand Slam tennis. As hypothesised, increased estimated WBGT increased total match doctor and trainer consults for heat related-incident, post-match heat-related incident consults (>32ºC) and calls for cooling devices (>28ºC). However, few matchplay characteristics were noticeably affected, with some signs of altered matchplay tactics mainly evident in reduced net approaches and increased aces, respectively. Finally, heat related incidence and behavioural characteristic markers in men's Grand Slam tennis appear to first increase in temperatures above 28ºC WBGT, although the most significant increases occur in temperatures above 32ºC WBGT, which conforms with the current extreme heat policy at the AO.

Practical Implications

- Tennis match play in conditions over 28ºC is associated with increased behavioral characteristics markers indicating reduced environmental comfort, while conditions above 32ºC WBGT showed an increase in heat related incidents such as heat related retirements.
- Medical staff at tennis tournaments that are at risk of high temperatures should be aware of the risks associated with heat illness and tennis match play in hot conditions.
- In high environmental temperatures coaching staff should also be aware of the potential changes to athlete's performance, particularly the decreased number of number of winners and net approaches, and an increase in the number of aces.

Author Acknowledgement

The authors thank Tennis Australia for making the data available for this study. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Three of the authors of the present study currently work for Tennis Australia. The present results do not constitute endorsement by Tennis Australia. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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Table 1. Medical and behavioral characteristics as a rate per 1000 hours (absolute occurrence) according to ACSM WBGT zones.

Variable	Zone 5 >32ºC	Zone 4 30-32ºC	Zone 3 28-30ºC	Zone 2 22-28ºC	Zone 1 <22ºC
Total match play time in minutes (number of matches)	8152 (30)	8642 (29)	5572 (18)	58954 (203)	16992 (60)
Retirement	29.4 (4)	13.9 (2)	0 (0)	12.2 (12)	3.5 (1)
Heat Stress Retirement	14.7 (2)	0 (0)	0 (0)	1.0 (1)	0 (0)
Trainer Call	80.7(11)	62.5 (9)	53.8 (5)	69.2 (68)	70.6(20)
Doctor Call	22.1 (3)	27.8 (4)	21.5 (2)	4.1 (4)	0 (0)
In match Heat Stress Call	29.4 (4)	6.9 (1)	0 (0)	3.1 (3)	7.1 (2)
Non Heat Stress Call	58.9 (8)	76.4 (11)	75.4 (7)	68.2 (67)	63.6 (18)
Post Match Heat Stress Call	29.4 (4)	6.9 (1)	0 (0)	0 (0)	0 (0)
Cooling Device Call	103.0 (14)	69.4 (10)	43.1 (4)	16.3 (16)	0 (0)
Water Calls	22.1 (3)	27.8 (4)	10.8 (1)	25.4 (25)	21.2 (6)

Table 2. Odds for Medical and Behavioral Characteristics according to ACSM WBGT zone.

	Zone 5 Reference Group[a]	**Odds ratio compared to zone 5**			
	Zone 5 >32ºC	**Zone 4 30-32ºC**	**Zone 3 28-30ºC**	**Zone 2 22-28ºC**	**Zone 1 <22ºC**
Player calling for trainer during match	0.22 ± 0.33 (<0.001)	0.82 ± 0.49 (0.684)	0.72 ± 0.59 (0.573)	0.90 ± 0.36 (0.760)	0.89 ± 0.41 (0.780)
Player calling for Doctor during match	0.05 ± 0.59 (<0.001)	1.407 ±0.79 (0.664)	1.12 ± 0.94 (0.906)	0.19 ± 0.78 (0.032)*	0 (0)
Call for trainer or doctor was Heat stress related	0.07 ± 0.52 (<0.001)	0.25 ± 1.13 (0.216)	0 (0)	0.10 ± 0.78 (0.004)*	0.24 ± 0.88 (0.103)
Post match heat stress consultation	0.07 ± 0.51 (<0.001)	0.25 ± 1.13 (0.216)	0 (0)	0 (0)	0 (0)
Non heat stress trainer or doctor call	0.15 ± 0.38 (<0.001)	1.52 ± 0.51 (0.407)	1.57 ± 0.57 (0.427)	1.29 ± 0.40 (0.534)	1.15 ± 0.46 (0.764)
Cooling device called for	0.304 ± 0.31 (<0.001)	0.69 ± 0.46 (0.413)	0.41 ± 0.61 (0.146)	0.14 ± 0.40 (<0.001)*	0 (0)
Water called for	0.053± 0.59 (<0.001)	1.41 ± 0.79 (0.664)	0.54 ± 1.17 (0.603)	1.14 ± 0.63 (0.834)	0.83 ± 0.75 (0.798)

Odds ratio for medical and behavioral characteristics when compared to zone 5: odd ratio ± standard error (p value). *=(p<0.05)
a The effect shown for the reference category are the odds of the outcome for zone 5 matches

Table 3: Match Characteristics and association of change per ACSM WBGT zone in ELO adjusted matches.

	WBGT 5 (ELO) >32°C	WBGT 4 (ELO) 30-32°C	WBGT 3 (ELO) 28-30°C	WBGT 2 (ELO) 22-28°C	WBGT 1 (ELO) <22°C	Association of change to WBGT zone
Match Duration (min) ø	144.8±49.9	144.8±50.1	142.5±47.1	140.8±41.7	137.0±42.1	+2.04 ±2.51 (0.418)
1st Serve Percentage (%)ø	60.8±7.1	60.5±7.3	61.3±7.8	62.6±7.2	62.5±7.1	-0.442± 0.413 (0.286)
Aces (count) ≠	10.2±7.4	10.2±7.3	10.1±7.5	8.5±6.7	8.2±6.5	+0.05± 0.018 (0.003)*
Double Faults (count) ≠	4.6±3.3	4.7±3.4	4.1±3.2	3.6±2.7	3.7±3.1	+0.045± 0.027 (0.091)
Winning on 1st Serve (%)ø	72.3±9.1	72.7±9.1	73.0±8.5	72.0±9.4	71.6±9.7	-0.442± 0.413 (0.286)
Winning on 2nd Serve (%)ø	50.5±10.9	50.8±11.1	52.2±10.5	50.9±10.5	51.0±10.5	-0.328± 0.618 (0.596)
Unforced Errors (count) ≠	31.1±20.9	30.9±20.4	31.5±18.2	27.7±20.9	28.2±21.0	-0.001± 0.010 (0.915)
Breakpoint Conversation (%)ø	44.8±17.9	44.5±18.1	45.4±20.3	44.6±18.2	46.0±18.5	+0.865± 1.114 (0.439)
Return Points Won (%)ø	36.1±8.5	35.9±8.6	34.3±10.1	34.5±12.3	34.4±12.9	+0.808± 0.607 (0.185)
Total Points Won (count) ø	108.0±36.9	107.6±36.2	106.2±33.6	108.3±32.4	105.1±32.8	+0.455± 1.889 (0.81)
Total points (count) ø	216.1±70.7	215.2±69.2	212.4±32.9	216.6±61.8	210.1±62.5	+0.910± 3.558 (0.798)
Winners (count) ≠	30.9±2.1	30.9±19.6	32.2±18.3	29.0±17.5	28.1±16.6	+0.007± 0.010 (0.48)
Net Approaches (count) ≠	15.9±14.0	15.9±13.7	18.6±15.2	18.9±16.1	18.0±15.3	-0.076± 0.013 (<0.001)*
Net Approaches Won (%)ø	66.6±14.8	60.5±15.5	67.0±13.6	65.9±14.6	65.8±15.0	+0.588± 0.876 (0.503)
Fastest Serve (km/h) ø	206.2±9.9	206.3±16.4	206.5±11.5	203.4±13.0	202.7±13.7	+0.164± 0.995 (0.869)
Average 1st Serve Speed (km/h) ø	181.9±9.1	182.3±9.4	183.7±11.4	182.0±8.0	181.8±7.9	-1.254± 0.733 (0.09)
Average 2nd Serve Speed (km/h) ø	148.6±10.2	148.7±10.1	150.0±11.8	147.6±9.1	147.5±8.8	-0.532± 0.782 (0.498)

Match characteristics: match characteristics average ±SE. Table gives match characteristics average across each temperature zone in from ELO adjusted matches characteristics and the association of change per change in WBGT zone as calculated through GLM analysis. –or+ indicates the direction of slope (- = decrease in hotter condition, + = increase in hotter conditions). ø denotes continuous data, data displayed as a change of the mean. ¥ denotes count data, data displayed as a rate ratio. *=(p<0.05).