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Articles

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Editorial

Dear friends,

There was a festive atmosphere in the Japan Sport Olympic Square on July 24th 2021 prior to the opening ceremony of the Tokyo 2020 Olympic Games. The run-up to the Tokyo 2020 Olympic Games was filled with concern about the ongoing pandemic. These Olympics have been like none that had come before, in that Tokyo was at all times under a state of emergency which lasted throughout the games. The games, though, were successfully completed. With the start of the Paralympic Games on August 24th the POC and IOC have provided the possibility for para athletes to also present their best. Despite the many negative effects of Covid-19, sport has again showed how important it is to stay positive and to get opportunity to compete in those uncertain times.

We all need to adjust to new circumstances. It would be remiss not to mention that this issue of Volume 3 is published during a global pandemic. Even though restrictions have influenced researchers' work, we know that the inability to hold tournaments and to meet and interact with players and coaches will have an impact on the number and content of research projects that can be conducted and subsequently reported.

It is a privilege to be given the opportunity to introduce the first issue of Volume 3 of the Journal. This volume contain papers that covered a range of sports science topics applied to racket sports, including sport psychology, statistics, biomechanics, motor control, motor learning and theory of training. The present issue brings 6 articles from different lines of racket sports.

The study conducted by Maridette Joyce D. Maranan and Arnulfo V. Lopez provides useful insights for practitioners in designing mental skills training geared towards optimal functioning and psychological wellness of young athletes. Table tennis student-athletes should be mentally tough as they train and perform under extreme pressure.

Michael Fuchs and Martin Lames investigate the »first offensive shot« (FOS), which is defined as the first shot after the serve without any kind of backspin/side-backspin. Compared to prevailing methods in table tennis match analysis, which are based on fixed shot numbers, taking the FOS as object of analyses of rally opening is an innovative new approach focusing on the tactical meaning of shots that is not expressed in shot number

Aline Miranda Strapasson and co-authors asked themselves: Are the technical and timing components of play different between two wheelchair classifications in Para-Badminton? Their study found that wheelchair athletes in one class showed a higher intensity (longer rally time and shorter pause time) and a higher frequency of technical actions (higher number of shuttle hits) when compared to a second class. This specific information can assist coaches during training to guide the development of the temporal and technical aspects of wheelchair play.

Another question come from Main Del Corto Motta and his co-authors: Knowledge and Competences of Racket Sports Coaches: What do They Think and Know? In general, knowledge and competences had high scores of attributed importance and perceived domain. However, knowledge of program implementation and evaluation, professional development of coaches and competence to develop the coaching philosophy had the lowest values of perceived domain.

What tennis player can do after serve, was investigated by Philipp Born and co-authors. Correlations were found between the placement of 4^{th} stroke and the return, between the 4th and the 3^{rd} stroke as well as between WTA and ITF players regarding all three strokes (return, 3^{rd} stroke, 4^{th} stroke).

Matthew James Wylde with co-authors sought to assess in their study the perception of racket sport coaches on the use of IMUs (inertial measurement unit) during training and competition. It was found that racket sports coaches were supportive of the use of IMUs during training. While coaches also indicated support for the use of IMUs during competition, no IMU placement was found to have a significantly positive response. This suggests that while coaches understand the benefits of collecting data from IMUs during competition, there remains concerns regarding inconvenience to the athlete, lack of comfort, and appearance.

I wish you pleasant reading and inspiration for new research projects and papers, which you can submit to IJRSS. We do not know how long we will live with the Covid-19 situation, but we are confident that researchers' interest for communicating their findings in a high quality forum will continue and so, we are sure, will the Journal.

Miran Kondric
Associate Editor
International Journal of Racket Sports Science

Exploring the Link between Athletic Identity, Self-compassion, Communication, and Mental Toughness of Table Tennis Student-Athletes

Exploración del vínculo entre identidad deportiva, autocompasión, comunicación y fortaleza mental de los estudiantes-atletas de tenis de mesa

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Abstract

Table tennis student-athletes should be mentally tough as they train and perform under extreme pressure. It is essential to identify other mental skills that will aid mental toughness development. Accordingly, the study focused on assessing athletic identity, self-compassion, and intra-team communication. The relationship between the constructs was also explored. A multi-part questionnaire was fielded to 230 college student-athletes participating in table tennis singles event. Findings indicate high levels of athletic identity and intra-team communication among the participants; while moderate levels for self-compassion and mental toughness. Structural equation modeling revealed the dynamic relationship between the constructs. On one hand, self-compassionate participants who highly recognize their role as athletes, and communicate with the team are more mentally tough. On the other hand, uncompassionate self-responding lead student-athletes to become mentally weak. The study provides useful insights for practitioners in designing mental skills training geared towards optimal functioning and psychological wellness of young athletes.

Keywords: *athletic identity; mental toughness; self-compassion; student-athletes; table tennis.*

Resumen

Los estudiantes-atletas de tenis de mesa deben tener fortaleza mental debido a que su entrenamiento y desempeño se dan bajo una presión extrema. Es fundamental identificar otras habilidades mentales que ayuden al desarrollo de la fortaleza mental. En consecuencia, el estudio se centró en la evaluación de la identidad deportiva, la autocompasión y la comunicación dentro del equipo. También se exploró la relación entre los constructos. Se envió un cuestionario de varias partes a 230 estudiantes-atletas universitarios que participaban en pruebas individuales de tenis de mesa. Los resultados indican altos niveles de identidad deportiva y comunicación dentro del equipo entre los participantes, a la vez que evidenció niveles moderados para la autocompasión y la fortaleza mental. Los modelos de ecuaciones estructurales revelaron la relación dinámica entre los constructos. Por un lado, los participantes autocompasivos que reconocen en gran medida su papel como atletas y se comunican con el equipo poseen mayor fortaleza mental. Por otro lado, la falta de autocompasión y el individualismo conllevan a la debilidad mental de los estudiantes-atletas. El estudio proporciona información útil para los profesionales a la hora de diseñar un entrenamiento de las habilidades mentales orientado al funcionamiento óptimo y al bienestar psicológico de los jóvenes atletas.

Palabras clave: *identidad deportiva; fortaleza mental; autocompasión; estudiantes-atletas; tenis de mesa.*

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INTRODUCTION

Table tennis athletes perform under extreme pressure (Ahsan & Mohammad, 2017). They are expected to render the play with high-intensity efforts, recover quickly between matches and rallies; and maintain cognitive function. The execution of goal-directed movements and specific motor skills, within a limited time frame, requires good planning and coordination (Faber, Nijhuis-Van Der Sanden, Elferink-Gemser, & Oosterveld, 2015; Mansec, Pageaux, Nordez, Dorel, & Jubeau, 2018; Zagatto, Papoti, dos Reis, Beck, & Gobatto, 2014). Thus, the athletes should not only be conditioned physically but mentally as well (Kondric, Zagatto, Sekulic, 2013) – someone who embodies psychological qualities such as mental toughness (Chu, Chen, I. Chen, L. Huang, & Hung, 2011). Mentally tough athletes are capable of efficiently performing again after a stressful experience. They face challenges head-on with confidence, persistence, and control (Sheard, Golby, & van Wersch, 2009). Adversely, young athletes who play an individual sport have been reported to exhibit low self-confidence (Yilmaz, Top, Çelenk, Akil, & Kara, 2015). They are also prone to internalize various types of feedback like losing a match or pressure to perform (Nixdorf, Frank, Hautzinger, & Beckmann, 2013). This highlights the need to identify other mental skills that will help develop mental toughness among table tennis student-athletes.

According to Vealey (2012), there are four types of mental skills needed to attain athletic success and address personal well-being – performance, personal development, foundation, and team skills. *Performance skills*, such as mental toughness, are crucial to skill execution. *Personal development skills*, like a clear self-concept, embody maturation indicators. *Foundation skills*, such as productive thinking, are fundamental sources found within the self. Team skills, such as team unity, produce an effective environment that facilitates the achievement of group objectives. The dynamics of these skills are also mirrored in athletic identity, self-compassion, and intra-team communication, respectively. Interestingly, studies have shown that some aspects of these skills may influence mental toughness.

Brewer and colleagues defined athletic identity as the “degree to which an individual identifies with the athletic role” (Gapin & Petruzzello, 2011, p. 1002). It has been noted that athletes with strong athletic identity set specific athletic goals. Goal setting gave them the reason to continue with their training and helped them identify themselves as athletes (Poucher & Tamminen, 2017). This characteristic is also salient for mentally tough individuals who exhibit goal-directed behaviors (Gucciardi, 2017). In the qualitative study of Connaughton, Hanton and Jones (2010), capacity beliefs and focus are intensified when athletes recognize their sense of accomplishment in sports participation. This indicates that the pleasant feelings associated with the athletic role can influence mental toughness.

Aside from athletic identity, mindfulness has been found to increase confidence to surpass challenges and general levels of mental toughness (Ajilchi et al., 2019; Sheard, 2012). It improved their attention, helped understand their feelings, reduced perceived stress, increased commitment in training routines, and facilitated behavioral and emotional regulation. Mindfulness is a characteristic of a self-compassionate individual coupled with kindness towards the self and recognition that they are not alone as they face adversities (Krieger, Berger, & Holtforth, 2017).

In a mental toughness training program, good communication skill has been identified as one of the areas that should be developed among athletes (Pattison, 2011). It can bring about unity (Sheryl & Bruce, 2005, as cited in Muthiaine, 2014), which in turn, can promote mental toughness among team members (Fourie & Potgieter, 2001, as cited in Young & Pearce, 2011).

The Basic Psychological Needs Theory (BPNT) also provides further support on the influence of athletic identity, self-compassion, and intra-team communication on mental toughness. This theory states that an individual’s psychological growth and development largely depend on the satisfaction of three needs – autonomy, competence, and relatedness (Deci & Ryan, 2015). People whose needs are satisfied are more likely to work towards the attainment of their goals with consistent effort compared to those whose needs are restrained. The kind of perseverance described herein is a “behavioral signature” of mental toughness (Gucciardi, Peeling, Duckera, & Dawson, 2016 p. 81). Thus, it can be inferred that student-athletes whose needs are satisfied are tougher mentally. Accordingly, athletic identity, self-compassion, and intra-team communication may satisfy the three basic needs. Ryan and Deci (2012) indicated that the main function of identity adoption (i.e athletic identity in the sports context) is to help fulfill basic psychological needs. Similarly, the concept of relatedness in BPNT also shares similarities with the common humanity dimension of self-compassion. Common humanity serves as an aid for athletes to perceive others who have similar experiences and facilitate acceptance of social support. It serves as a vital strategy to cope with setbacks such as poor performance, injury, or an unwanted outcome in a competition (Mosewich, Crocker, & Kowalski, 2014). Adopting effective intra-team communication strategies also fosters needs satisfaction. These consist of exchanging messages that orient, stimulate, and evaluate the performance of each member (Onag & Tepeci, 2014), which is akin to having an autonomy-supportive environment that is needed to satisfy the needs. By and large, BPNT posits that the satisfaction of the three basic psychological needs cultivates a more internalized behavior and self-determined motivation (Barbeau et al., 2009, as cited in Reifsteck, Gill, & Labban, 2016). The present study argued that this internalized behavior and self-determined motivation can be translated into mental toughness.

While traces can be found in the extant literature on how athletic identity, self-compassion, and intra-team communication may influence mental toughness, no research has been made to directly test their relationship. Also, there is scarcity in literature regarding the assessment of mental skills of table tennis student-athletes. To address these gaps, this study was pursued to (1) identify table-tennis student-athletes' level of athletic identity, self-compassion, intra-team communication, and mental toughness, and (2) test the relationship between the constructs. From the theoretical expectation and conceptual standpoint, the hypothesis, there is a significant relationship between the constructs, was tested (Figure 1).

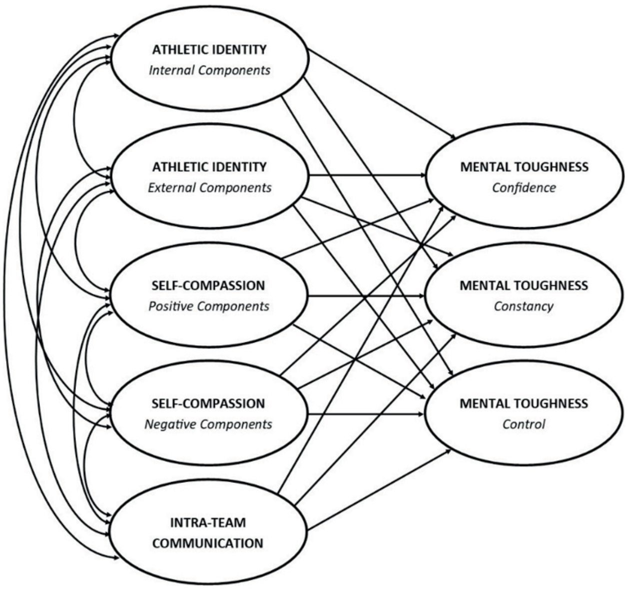

Figure 1. Hypothesized model showing the relationship between the constructs.

MATERIALS AND METHODS

Participants

Participants were 230 college student-athletes (Mage= 20 years; SD=1) playing in table tennis singles event. Total population sampling was used as there is a limited number of student-athletes playing the said sport. They were selected from the 25 member schools of different athletic associations in the Philippines. More than half of the participants are male (57%, n=131). While most of them are in their first two years in tertiary education (1st year: 44%, n=102; and 2nd year: 36%, n=83), the majority started as junior student-athletes (89.6%, n=206). They have been playing table tennis for an average of 8 years (SD=3).

Design and Procedures

Descriptive and correlational designs were utilized in this study. Before collecting the data, approval was sought from the Institutional Ethics Review Committee of the [name of the institution; removed for anonymity]. Participants voluntarily signed an informed consent form that includes pertinent information about the study as well as their rights. The following modified questionnaires were utilized to measure the constructs (original developers granted permission to use and modify the instrument to include translation of statements to the local language; pilot testing was also conducted):

Athletic Identity Measurement Scale-Plus (AIMS-Plus). This scale was originally developed by Cieslak (2004). It consists of 20 items and demonstrates good internal consistency (α=.87). Confirmatory factor analysis revealed acceptable indices (CMIN/df = 2.146, RMSEA=0.071, CFI=.902, IFI = .904) that support the original components of athletic identity – internal and external. The internal components include *Positive Affectivity* [good feelings in sport participation], *Self-identity* [awarenes of the athletic role], and *Negative Affectivity* [negative reactions towards undesirable athletic outcomes]. The external components are *Exclusivity* [self-worth is gauged through sports participation] and Social Identity [awareness that others see him as an athlete]. Participants rated the items on a 7-point scale ranging from 1 (*strongly disagree*) to 7 (*strongly agree*).

Self-compassion Scale (SCS). Participants rated the 24 items on a 5-point scale where endpoints range from 1 (*almost never*) to 5 (*almost always*). Confirmatory factor analysis revealed indices that shows adequate fit for the two-factor self-compassion model of Neff (2003) – positive (CMIN/df = 1.458, RMSEA=0.045, CFI=.969, IFI = .970) and negative (CMIN/df = 1.876, RMSEA=0.062, CFI=.945, IFI = .946). Positive self-compassion includes *Self-Kindness* [being kind and understanding to oneself], *Common Humanity* [acknowledgment that he is part of a larger community], and *Mindfulness* [neutrally embracing painful feelings/thoughts]. Negative self-compassion comprises of *Self-Judgment* [making harsh/critical judgment about the self], Isolation [sees self as separate from people], and *Over-identification* [excessively ruminating over negative emotions/cognitions]. The scale demonstrates good internal consistency (*α*=.87).

Scale of Effective Communication in Team Sports (SECTS-2). This scale was developed by Sullivan and Short (2011) and was used in this study to assess the three communication strategies used by the participants, namely: *Acceptance* [considers welfare and appreciates everyone], *Distinctiveness* [use of verbal and non-verbal communication tools that makes the group unique] and *Positive Conflict* [openly and calmly share thoughts, feelings, and disparities]. The three-factor model was subjected to confirmatory factor analysis and revealed acceptable fit indices (CMIN/df = 1.580, RMSEA=0.050, CFI=.981, IFI = .982). It also demonstrates good internal consistency (α=.86). A total of 11 items were rated by the participants on a

7-point scale ranging from 1 (*hardly ever*) to 7 (*almost always*).

Sports Mental Toughness Questionnaire (SMTQ). This scale was developed by Sheard et al. (2009) and was used to measure the three components of mental toughness, namely: *Confidence* [capacity belief to attain goals and outperform opponents], *Constancy* [determination to commit to tasks], and *Control* [ability to manage emotions/behavior]. The results of confirmatory factor analysis showed indices of a good model fit (CMIN/df = 1.252, RMSEA=0.033, CFI=.982, IFI = .983), and Cronbach alpha revealed an acceptable reliability index (α=.78). Participants rated 14 items on a 4-point scale, ranging from 1 (*not at all true*) to 4 (*very true*).

Analysis

Means and standard deviations were generated in SPSS 22.0 to determine the levels of athletic identity, self-compassion, intra-team communication, and mental toughness. Higher scores in the scales indicate higher levels in the measured construct. Structural Equation Modeling, through AMOS 24.0, was used to determine the relationship among the variables. Four common measures were utilized to assess the model's goodness of fit: chi-square/degrees of freedom (CMIN/df), comparative fit index (CFI), incremental fit index (IFI), and root mean square error of approximation (RMSEA). Carmines and McIver's (1981) ratio rule together with Browne and Cudeck's (1993) criteria served as indicators of adequate fit: CMIN/df in the range of 2 to 1, CFI and IFI ≥ .90, and RMSEA Score ≤ .08. The magnitude of the regression coefficients was interpreted using the guidelines offered by Kline (2005): small effect for .10 values or less, a medium effect for values around .30, and .50 or above for a large effect.

RESULTS

Descriptive Results

Table tennis student-athletes in the study have high levels of athletic identity (*M*=57, SD=7). Both internal (*M*=73, SD=9) and external (*M*=40, SD=7) components received a high rating. Among the sub-components of athletic identity, positive affectivity received the highest mean rating (*M*=73, SD=9). Participants consider that their sport participation brings a positive impact on their lives and it makes them happy. Conversely, they exhibit moderate levels of social identity (*M*=18, SD=5). They strongly disagree that they participate in sport for recognition or fame.

The participants' self-compassion is found to be at moderate levels (*M*=3.33, SD=0.421). While they highly manifest positive self-compassion behaviors (*M*=3.94, SD=.574), they also show moderate levels of uncompassionate self-responding (*M*=3.35, SD=.861). They still feel inadequate when faced with failures and takes them too seriously even if they can regulate their emotions well.

As for intra-team communication, they always use effective strategies (*M*=5.71, SD=.896). Acceptance (*M*=5.93, SD=.975) received the highest mean rating. They usually ensure that all team members are included when they communicate. They also trust each other.

Results also revealed that the table tennis student-athletes exhibit moderate levels of mental toughness (*M*=40, SD=6). They have high levels of confidence (*M*=19, SD=3) and constancy (*M*=7, SD=1) but their control is at moderate levels (*M*=15, SD=4). They do recognize their unique qualities as athletes. Nonetheless, they get anxious, angry, and frustrated when things do not go their way.

Structural Equation Modeling Results

The relationships between athletic identity, self-compassion, intra-team communication, and mental toughness were analyzed through the use of Structural Equation Modeling (SEM). Figure 2 shows the emerging model. It generated indices that demonstrate an adequate (CMIN/df = 1.785, RMSEA=0.059) and a very good fit (CFI=.902, IFI = .904).

In the model, the positive correlation between athletic identity, positive self-compassion, and intra-team communication can be noted. The interplay between these variables influences the mental toughness components in a positive light. The more student-athletes exhibit high levels of said skills, the more they become mentally tough. Standardized regression weights of .233, .405, and .256 were calculated for the direct impact of external athletic identity, positive self-compassion, and intra-team communication to the constancy component of mental toughness. The 48.2% variance in the table tennis student-athletes' constancy can be explained by these mental skills. A direct association can also be noted between external athletic identity (.265), positive self-compassion (.464), and the confidence component of mental toughness. Nevertheless, an inverse relationship was revealed between negative self-compassion and confidence (-.217). Uncompassionate behaviors are accounted for the 42.4% variance of the student-athletes' confidence. It can also be noted from the figure that uncompassionate self-responding (-.737), while not related to other constructs, negatively influences the control component of mental toughness and can be accounted for its 54.3% variance.

The figure also shows that the internal component of athletic identity is not directly associated to any of the components of mental toughness but it is related to external athletic identity (.845), positive self-compassion (.490), and intra-team communication (.403). This indicates the indirect relationship between internal athletic identity and mental toughness.

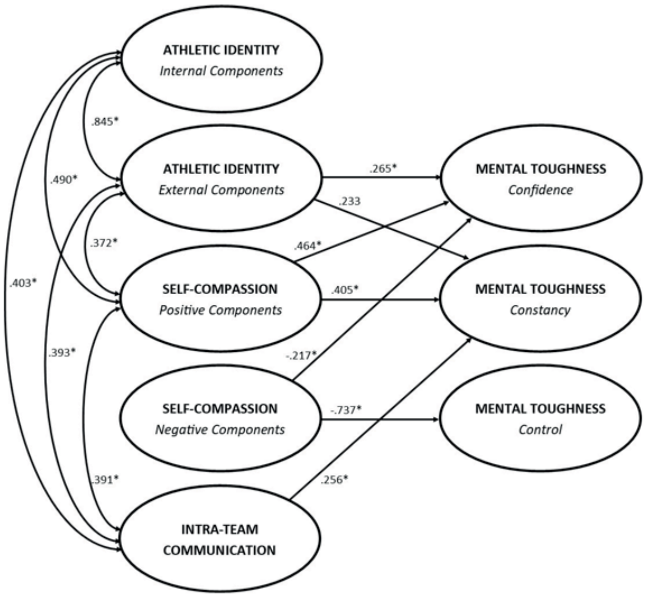

Figure 2. Results of structural equation modeling showing standardized estimates of the proposed model with regression coefficients significant at p<0.05, *p<0.01.

Generally, the model revealed the medium to a large direct and indirect effect of the components of athletic identity, self-compassion, and intra-team communication on mental toughness. Among these mental skills, negative self-compassion can be considered as the most influential construct that affects mental toughness followed by positive self-compassion. These results show the acceptance of the hypothesis raised in the study.

DISCUSSION

The objectives of the present study were twofold. The first objective was to assess the levels of athletic identity, self-compassion, intra-team communication, and mental toughness among the participants. It was found out that table tennis student-athletes have high levels of athletic identity and intra-team communication, while moderate levels for self-compassion and mental toughness.

The high levels of athletic identity among the participants may be attributed to the fact that they are involved in sports at an early age. Some of them started playing table tennis since they were kids and most of them are student-athletes since high school. In the sports context, identity as an athlete starts to form during high school. At this stage, student-athletes recognize the need for time and psychological commitment to become successful in the field. When they reach college, their identities become crystallized as they strongly identify with their athletic role (Johnson & Migliaccio, 2009, as cited in Heird & Steinfeldt, 2013). Their early sports involvement could also explain their frequent use of effective communication strategies. They are trained on how to properly connect with others. Sports is a highly interactive activity where athletes can interact with various individuals, these include but are not limited to their teammates, coaches, and the audience. It is a great avenue for young individuals to learn good communication skills. Some studies have demonstrated the ability of sports to develop communication efficacy (Ishak, 2017).

The moderate levels of mental toughness may be due to their inability to control emotions and direct behavior at times of difficulties. While they are confident about their abilities and are committed to their goals, they still worry about their performance. This anxiety leads to their inability to focus well during sports performance (Chen, I. Chang, Hung, Chen, L. & Hung et al., 2010). They become preoccupied with poor skill execution instead of finding ways on how to improve their tactics. This is consonant with the study of Martinent and Ferrand (2009) where they found the facilitating and debilitating roles of emotions among table tennis athletes. Anxiety and other emotions (e.g. anger and hope) brought about positive influences, but these also reduced their concentration, motivation, and confidence. These emotions also brought forth maladaptive behaviors, like committing errors and ill-timed forceful strokes. Similarly, table tennis athletes who are inclined to either express anger outwardly or suppress angry feelings are considered to exhibit poor psychological adjustment (González-García & Martinent, 2020). These findings demonstrate that emotions, if not managed well, can affect the mental state and performance of athletes. The difficulty of the participants to control their emotions is confirmed by their moderate levels of self-compassion. They sometimes overidentify, isolate, and judge themselves when faced with adversity. These confirm the need to develop the mental skills of table tennis student-athletes, particularly self-compassion and mental toughness.

In light of the aforementioned findings, it is important to identify constructs that are related to them. This is the focus of the second objective of the study. Findings revealed that student-athletes who prioritize their sport and cognizant of their social roles are more responsible, committed, and confident. This can be attributed to the sense of obligation that athletes may feel as they continue to participate in sport (Scanlan, T., Chow, Sousa, Scanlan, L., & Knifsend, 2016). It is imperative for them to continuously and consistently plan and perform tasks that would make them better. This is because sport defines their day-to-day lives and people see them as athletes. The external forces that complete their athletic identity shape their sporting attitude. They try to seek the ideals attached to being an athlete – making sure that they attend to the social roles and expectations. As they do this, the more people will recognize them, and the more that they would feel that they belong to a community that supports them as athletes. One of these communities is their team. As they feel accepted in this group, they will not hesitate to communicate with them. This creates a positive team atmosphere.

Athletes are more likely to evaluate stressors as challenging experiences if they feel free to express their feelings, can receive guidance, and fulfill demands with support from others. (Ntoumanis, Edmunds, & Duda, 2009). They will engage more in volitional behaviors to improve and accomplish their goals as they feel the support of the team. This support can lead to their commitment to perform well. They will spend more time in sporting activities, which in turn may strengthen capacity beliefs. Beaumont, Maynard and Butt (2015) noted that one way to develop and maintain confidence in sport is through the awareness of the athlete's unique strength and how to utilize it to his advantage. This awareness will only materialize if student-athletes will work together with the team during training and competition. Continuous team interaction also enables the formation of identities and prompts the differentiation of self from others (Anderson & Coleman, 2008, as cited in Da Silva et al., 2016). Thus, student-athletes who engage more with the team will have more opportunities to identify their unique abilities that will later define their confidence. These lend credence to the notion that the sporting abilities of the athletes are reinforced by society as they perform their obligations (Beamon, 2012).

Nevertheless, external athletic identity and intra-team communication are not the only constructs that can influence mental toughness. Findings show that those who exhibit higher levels of positive self-compassion have higher levels of confidence and constancy as well. Karanika and Hogg (2016) indicated that self-compassionate individuals are not defensive and strive to take a clear picture of their strengths and weakness. As indicated earlier, the acknowledgment of one's capacities is the first step in boosting one's confidence. Likewise, athletes who are capable of accepting their weaknesses with kind understanding and balanced awareness are more likely to become committed to their goals. This is because they can nurture and make themselves better in a safe and non-judgmental environment (Breines & Chen, 2012). Consequently, those who judge themselves harshly cast doubts on their inherent abilities. They will not be able to fully recognize their competence as their minds are clouded with their flaws and inadequacies. Uncompassionate self-responding does not only influence confidence in a negative light. It also affects the athlete's control. The more student-athletes become self-critical, feels isolated, and are preoccupied with their negative thoughts and feelings, the more that they lose their control. They are consumed by their pessimistic attitude towards themselves and are wrapped up by emotions that are harmful to sports performance. They are unable to focus on their tactics and techniques. These findings are clear indications that self-compassion provides young individuals a "secure, positive sense of self" (Barry, Loflin, & Doucette, 2015) and its opposite will lead to a thwarted perception of their potentials making them mentally weak.

Interestingly, negative self-compassion is not directly related to athletic identity, positive self-compassion, and intra-team communication. This finding provides mixed support for the study of Neff et al. (2018). On one hand, the present study shows that the two components of self-compassion are not interrelated – they are considered as two separate units; this is in contrast to the contention of Neff et al. (2018). On the other hand, this study does acknowledge the varying influence of both components on specific outcomes. The emerging model revealed that positive self-compassion is correlated to athletic identity and intra-team communication and has a medium impact on confidence and constancy. On the contrary, negative self-compassion has a large effect on the control component of mental toughness and is not related to athletic identity and intra-team communication. Taking these into consideration, each component of self-compassion should be given focus when developing the mental skills of table tennis student-athletes. Positive self-compassion should be maintained at high levels while reducing negative self-compassion.

Considering the importance of compassionate self-responding, it is noteworthy to examine its positive relationship with intra-team communication. The more student-athletes engage in effective communication, the more that they nurture a positive atmosphere where they can openly discuss performance issues/concerns. This will then prompt them to become kind to themselves as they are aware that there are people who are ready to accept them whatever their performance outcomes are. They will feel that they are not alone in their endeavors. The sense of belonging that they experience from the team makes them feel more connected to others. This positive experience can prompt student-athletes to accept, respect, and trust their team as well.

It is also important to point out the indirect influence of internal athletic identity on mental toughness. It further substantiates the notion of satisfying all the basic needs including relatedness to make student-athletes mentally tough. The internal component of athletic identity, taken alone, deals with self-evaluation and interpretation of the athlete without the influence of society. Thus, internal athletic identity cannot directly affect mental toughness as the presence of others is considered essential in making an athlete mentally tough. As Galli and Vealey (2008, as cited in Mahoney, Ntoumanis, Mallett, & Gucciardi, 2014) noted, athletes are motivated to recalibrate their performance level, functioning, and development in the presence of social support. They can adapt well amidst difficulties if they feel the connection to a wider social fabric – a dimension tapped by external athletic identity, positive self-compassion, and intra-team communication. Aside from this, it should also be noted that some internal components of athletic identity have a contradictory influence on the anxiety of table tennis athletes. A clear self-concept decreases anxiety, which may help them cope with challenges, but high levels of negative affectivity can elevate it (Masten, Tušak, & Faganel, 2006). Thus, having high levels of internal athletic identity may not directly influence the ability of the athletes to face challenges head-on. Nevertheless, it is worth noting that internal athletic identity was taken here as a collective construct. Breaking down its components may provide alternative results on its influence on mental toughness.

While the study offers insights on which mental skills are to be developed among these young table tennis athletes, some limitations should be noted. One of which is the self-report measures that were utilized and may have resulted in biased ratings of the constructs. Also, due to the sampling used in the study, few of the participants recently joined the team and have limited experience as student-athletes. Future research may consider using additional measures to confirm the results and consider playing years in the inclusion criteria. Comparison of the mental skills according to a variety of profiles (e.g. age, number of years as student-athletes, etc.) may also yield interesting results that could aid in developing suitable training programs for these athletes. Extending the study to include other individual and team sports may also provide a more conclusive finding on the link between athletic identity, self-compassion, intra-team communication, and mental toughness.

CONCLUSION

The findings provide evidence that the mental skills capable of satisfying psychological needs can make table tennis student-athletes mentally tough. The dynamic link that exists among the skills calls sports practitioners to be judicious in developing mental toughness. In light of the findings, it is recommended to improve the levels of mental toughness by tapping on athletic identity, intra-team communication, and self-compassionate behaviors. Among these, the focus should be given to self-compassion. It should be noted that training student-athletes to engage more in self-compassionate behaviors will not lead to addressing uncompassionate self-responding. Thus, the latter should be treated as a separate construct needing more attention as it can greatly influence mental toughness negatively. Table tennis student-athletes should not only learn how to be self-compassionate but should also know how to hold back or at least lessen the uncompassionate behavior towards the self.

REFERENCES

Ahsan, M., & Mohammad, A. (2017). Mental toughness as a determinant factor of performance in table tennis. *European Journal of Physical Education and Sport Science*, *3*(12), 194–203. https://doi.org/10.5281/zenodo.1092745

Ajilchi, B., Amini, H. R., Reza, H., Ardakani, Z. P., Zadeh, M. M., & Kisely, S. (2019). Applying mindfulness training to enhance the mental toughness and emotional intelligence of amateur basketball players. *Australasian Psychiatry*, *27*(3), 291–296. https://doi.org/10.1177/1039856219828119

Barry, C., Loflin, D., & Doucette, H. (2015). Adolescent self-compassion: Associations with narcissism, self-esteem, aggression, and internalizing symptoms in at-risk males. *Personality and Individual Differences*, *77*, 118–123. http://dx.doi.org/10.1016/j.paid.2014.12.036

Beamon, K. (2012). "I'm a baller": Athletic identity foreclosure among African-American former student-athletes. *Journal of African American Studies*, *6*(1), 195–208. https://doi.org/10.1007/s12111-012-9211-8

Beaumont, C., Maynard, I. W., & Butt, J. (2015). Effective ways to develop and maintain robust sport-confidence: Strategies advocated by sport psychology consultants. *Journal of Applied Sport Psychology*, *27*(3), 301-318. https://doi.org/10.1080/10413200.2014.996302

Breines, J. G., & Chen, S. (2012). Self-compassion increases self-improvement motivation. *Personality and Social Psychology Bulletin*, *38*(9), 1133–1143. https://doi.org/10.1177/0146167212445599

Browne, M.W., & Cudeck, R. (1993). Alternative ways of assessing model fit. In K. A. Bollen & J. S. Long (Eds.), *Testing structural equation models* (pp. 136–162). Sage.

Carmines, E. G., & McIver, J.P. (1981). Analyzing models with unobserved variables. In G. W. Bohrnstedt & E. F. Borgatta (Eds.), *Social measurement: Current issues* (pp. 65-115). Sage.

Chen, I. T., Chang, C. W., Hung, C. L., Chen, L. C., & Hung, T. M. (2010). Investigation of underlying psychological factors in elite table tennis players. *International Journal of Table Tennis Sciences*, *6*, 48-50.

Chu, C. Y., Chen, I. T., Chen, L. C., Huang, C. J., & Hung, T. M. (2011, May 5-7). Sources of psychological states related to peak performance in elite table tennis player. *International Journal of Table Tennis Sciences*, *7*, 84–88.

Cieslak, T. J., II. (2004). *Describing and measuring the athletic identity construct: Scale development and validation* [Doctoral Dissertation, Ohio State University]. Retrieved from https://www.ohiolink.edu/

Connaughton, D., Hanton, S., & Jones, G. (2010). The development and maintenance of mental toughness in the World's Best Performers. *The Sport Psychologist*, *24*(2), 168–193. https://doi.org/10.1123/tsp.24.2.168

Da Silva, W. R., Ferrari, E. P., Medeiros, T. E., de Freitas, K. T., Tkac, C. M., & Cardoso, F. L. (2016). "Athletic Identity Measurement Scale": Translation, adaptation, and validation for Brazil. *Motriz, Rio Claro*, *22*(1), 42-47. http://dx.doi.org/10.1590/S1980-65742016000100006

Deci, E. L., & Ryan, R. M. (2015). Self-determination theory. In J. D. Wright (Ed.), *International Encyclopedia of the Social & Behavioral Sciences Volume* (2nd ed., vol. 21, pp. 486-491). Elsevier.

Faber, I. R., Nijhuis-Van Der Sanden, M. W., Elferink-Gemser, M. T., & Oosterveld, F. G. (2015). The Dutch motor skills assessment as tool for talent development in table tennis: A reproducibility and validity study. *Journal of Sports Sciences*, *33*(11), 1149–1158. https://doi.org/10.1080/02640414.2014.986503

Gapin, J., & Petruzzello, S. J. (2011). Athletic identity and disordered eating in obligatory and non-obligatory runners. *Journal of Sports Sciences*, *29*(10), 1001-1010. https://doi.org/10.1080/02640414.2011.571275

González-García, H., & Martinent, G. (2020). Perceived anger profiles in table tennis players: Relationship with burnout and coping. *Psychology of Sport and Exercise*, *50*, 101743. https://doi.org/10.1016/j.psychsport.2020.101743

Gucciardi, D. (2017). Mental toughness: Progress and prospects. *Current Opinion in Psychology*, *16*, 17–23. https://doi.org/10.1016/j.copsyc.2017.03.010

Gucciardi, D., Peeling, P., Duckera, K.J., & Dawson, B. (2016). When the going gets tough: Mental toughness and its relationship with behavioural perseverance. *Journal of Science and Medicine in Sport*, *19*(1), 81–86. https://doi.org/10.1016/j.jsams.2014.12.005

Heird, B. E., & Steinfeldt, J. A. (2013). An interpersonal psychotherapy approach to counseling student-athletes: Clinical implications of athletic Identity. *Journal of College Counseling*, *16*(2), 143-157. https://doi.org/10.1002/j.2161-1882.2013.00033.x

Ishak, A. W. (2017). Communication in sports teams: A review. *Communication Research Trend*, *36*(4), 1-38.

Karanika, K. & Hogg, M. (2016). Being kind to ourselves: Self-compassion, coping, and consumption. *Journal of Business Research*, *69*(2), 760–76. https://doi.org/10.1016/j.jbusres.2015.07.042

Kline, R. B. (2005). *Principles and practice of structural equation modeling* (2nd ed.). The Guilford Press.

Kondric, M., Zagatto, A. M., & Sekulic, D. (2013). The physiological demands of table tennis: A review. *Journal of Sports Science and Medicine*, *12*(3), 362–370.

Krieger, T., Berger, T., & Holtforth, M. (2017). The relationship of self-compassion and depression: Cross-lagged panel analyses in depressed patients after outpatient therapy. *Journal of Affective Disorders*, *202*, 39–45. https://doi.org/10.1016/j.jad.2016.05.032

Mahoney, J., Ntoumanis, N., Mallett, C., & Gucciardi, D. (2014). The motivational antecedents of the development of mental toughness: A self-determination theory perspective. *International Review of Sport and Exercise Psychology*, *7*(1), 184–197. https://doi.org/10.1080/1750984X.2014.925951

Mansec, Y. L., Pageaux, B., Nordez, A., Dorel, S., & Jubeau, M. (2018) Mental fatigue alters the speed and the accuracy of the ball in table tennis. *Journal of Sports Sciences*, *36*(23), 2751-2759. https://doi.org/10.1080/02640414.2017.1418647

Martinent, G., & Ferrand, C. (2009). A naturalistic study of the directional interpretation process of discrete emotions during high-stakes table tennis matches. *Journal of Sport and Exercise Psychology*, *31*, 318–336. https://doi.org/10.1123/jsep.31.3.318

Masten, R., Tušak, M., & Faganel, M. (2006). Impact of identity on anxiety in athletes. *Kinesiology*, *38*(2), 126–134.

Mosewich, A., Crocker, P., & Kowalski, K. (2014). Managing injury and other setbacks in sport: Experiences of (and resources for) high-performance women athletes. *Qualitative Research in Sport, Exercise and Health*, *6*(2), 182–204. https://doi.org/10.1080/2159676X.2013.766810

Muthiaine, M. C. (2014). *Relationship between team cohesion and sports performance among basketball teams in the 2010 National League in Kenya* (Master's thesis, Kenyatta University). Retrieved from https://ir-library.ku.ac.ke

Neff, K. D. (2003). Self-Compassion: An alternative conceptualization of a healthy attitude toward oneself. *Self and Identity*, *2*(2), 85–101. https://doi.org/10.1080/15298860309032

Neff, K. D., Long, P., Knox, M. C., Davidson, O., Kuchar, A., Costigan, A., Williamson, Z., Rohleder, N., Tóth-Király, I., & Breines, J. G. (2018). The forest and the trees: Examining the association of self-compassion and its positive and negative components with psychological functioning. *Self and Identity*, *17*(6), 627–645. https://doi.org/10.1080/15298868.2018.1436587

Nixdorf, I., Frank, R., Hautzinger, M., & Beckmann, J. (2013). Prevalence of depressive symptoms and correlating variables among German elite athletes. *Journal of Clinical Sport Psychology, 7*(1), 313–326. https://doi.org/10.1123/jcsp.7.4.313

Ntoumanis, N., Edmunds, J., & Duda, J. L. (2009). Understanding the coping process from a self-determination theory perspective. *British Journal of Health Psychology*, *14*(2), 249–260. https://doi.org/10.1348/135910708X349352

Onag, Z., & Tepeci, M. (2014). Team effectiveness in sport teams: The effects of team cohesion, intra-team communication and team norms on team member satisfaction and intent to remain. *Procedia - Social and Behavioral Sciences*, *150*, 420–428. https://doi.org/10.1016/j.sbspro.2014.09.042

Pattison, S. (2011). *The development and implementation of a mental toughness training programme for young cricketers* (Master's Thesis, Rhodes University). Retrieved from https://core.ac.uk/download/pdf/145054795.pdf

Poucher, Z., & Tamminen, K. (2017). Maintaining and managing athletic identity among elite athletes. *Journal of Sport Psychology*, *26*(4), 63–67.

Reifsteck, E. J., Gill, D. L., & Labban, J. D. (2016). "Athletes" and "Exercisers": Understanding identity, motivation, and physical activity participation in former college athletes. *Sport, Exercise, and Performance Psychology*, *5*(1), 25–38. https://doi.org/10.1037/spy0000046

Ryan, R. M., & Deci, E. L. (2012). Multiple identities within a single self: A self-determination theory perspective on internalization within contexts and cultures. In M. R. Leary & J. P. Tangey (Eds.), *Handbook of self and identity* (2nd ed., pp. 225-246). Gulliford Press.

Scanlan, T. K., Chow, G. M., Sousa, C., Scanlan, L. A., & Knifsend, C. A. (2016). The development of the sport commitment questionnaire-2 (English version). *Psychology of Sport & Exercise*, *22*, 233–246. https://doi.org/10.1016/j.psychsport.2015.08.002

Sheard, M. (2012). *Mental toughness: The mindset behind sporting achievement*. Routledge.

Sheard, M., Golby, J., & van Wersch, A. (2009). Progress toward construct validation of the Sports Mental Toughness Questionnaire (SMTQ). *European Journal of Psychological Assessment*, *25*, 186–193.

Sullivan, P., & Short, S. (2011). Further operationalization of intra-team communication in sports: An updated version of the Scale of Effective Communication in Team Sports (SECTS-2). *Journal of Applied Social Psychology*, *41*(2), 471–487. https://doi.org/10.1111/j.1559-1816.2010.00722.x

Vealey, R. (2012). Mental skills training in sport. In G. Tenenbaum & R. Eklund (Eds.), *Handbook of Sport Psychology* (3rd ed., pp. 287–309). John Wiley & Sons.

Yilmaz, T., Top, E., Çelenk, Ç., Akil, M., & Kara, E. (2015). Evaluating the self-confidence levels of teams and individual athletes at the age of 14-16 according to several variables. *Ethno Med*, *9*(2), 203–207. https://doi.org/10.1080/09735070.2015.11905436

Young, J. A., & Pearce, A. J. (2011). Understanding, developing and maintaining mental toughness in tennis. *Medicine and Science in Tennis*, *16*(2), 18–22. http://hdl.handle.net/10536/DRO/DU:30045198

Zagatto, A. M., Papoti, M., dos Reis, I. G. M., Beck, W. R., & Gobatto, C. A. (2014). Analysis of cardiopulmonary and metabolic variables measured during laboratory and sport-specific incremental tests for table tennis performance prediction. *Science and Sports*, *29*(2), 62–70. https://doi.org/10.1016/j.scispo.2013.08.001

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Original article

First Offensive Shot in Elite Table Tennis

El primer golpe ofensivo en el tenis de mesa de élite

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Abstract

From the very first shots in table tennis, players face a basic tactical decision: either return the ball short and defensively or attack it with an offensive shot. Thus, the real turntable of a rally is the shot - in this study called "first offensive shot" (FOS) – which is the transition from defensive to offensive play. This study investigates the FOS, which is defined as the first shot after the serve without any kind of backspin/side-backspin, for 90 matches (nrally = 7449) of the 2016 Rio Olympic Games. The FOS parameters – laterality, technique and position to the table at the point of contact – and the respective winning probabilities are analysed. The influences of sex and the players' ranking (resulting in three different match categories) on those parameters are studied. Descriptive statistics about the incidences of the FOSs show that four typical FOSs cover 98% of all FOSs. Chi-square tests reveal a significant relation between sex and these typical FOSs. Regarding the match categories, the tests prove a significant relation between match categories and FOS tactics for both genders. A difference in the FOS tactics between the serving and the receiving player is found as well. The winning probabilities show that using topspin (Forehand and Backhand) as FOS was an advantage in every match category, whereas using flip as FOS led mostly to a winning probability below 50% for the FOS player. Compared to prevailing methods in table tennis match analysis, which are based on fixed shot numbers, taking the FOS as object of analyses of rally opening is an innovative new approach focusing on the tactical meaning of shots that is not expressed in shot number.

Keywords: *First offensive shot, racket sports, table tennis, match analysis.*

Resumen

En los primeros golpes del tenis de mesa, los jugadores se enfrentan a una decisión táctica básica: devolver la pelota en corto y de forma pasiva o atacarla con un golpe ofensivo. En el primer caso, hay menos riesgo, pero no hay presión para hacer el punto; en el segundo caso, se crea presión, pero con un alto riesgo porque el servicio y los previos golpes "pasivos" tratan de dificultar al máximo un golpe ofensivo, que normalmente es corto y plano. Por lo tanto, el verdadero punto de inflexión de un peloteo es este golpe –en este estudio llamado "primer golpe ofensivo" (FOS, por su sigla en inglés)–, el cual es la transición del juego pasivo al ofensivo. Este estudio investiga el FOS, el cual se define como el primer golpe después del servicio sin ponerle efecto a la pelota, para 90 partidos (n_{rally} = 7449) de los Juegos Olímpicos de Río 2016. Se analizan los parámetros del FOS –lateralidad, técnica y posición en la mesa en el punto de contacto– y las respectivas probabilidades de victoria. Se estudian las influencias del género y de la clasificación de los jugadores (lo que da lugar a tres categorías de partidos diferentes) en esos parámetros. La estadística descriptiva sobre las incidencias de los FOS muestra que cuatro FOS típicos cubren el 98

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% de todos los FOS. Las pruebas x^2 revelan una relación significativa entre el género y estos FOS típicos. En cuanto a las categorías de los partidos, las pruebas demuestran una relación significativa entre las categorías de los partidos y la táctica del FOS para ambos géneros. También se encontró una diferencia en la táctica del FOS entre el jugador que sirve y el que recibe. Las probabilidades de victoria muestran que usar el efecto (de derecha o de revés) como FOS fue una ventaja en todas las categorías de los partidos, mientras que el uso del *flip* como FOS condujo en su mayoría a una probabilidad de victoria inferior al 50 % para el jugador del FOS. Excepto por el *flip* derecho en los partidos femeninos, siempre fue una mayor ventaja para el jugador del FOS si este podía terminar el peloteo de último con el ataque subsiguiente después del FOS, lo que significa que la probabilidad de victoria para el jugador del FOS disminuyó en los peloteos más largos. En comparación con los métodos predominantes en el análisis de partidos de tenis de mesa, que se basan en los números fijos de golpes, tomar el FOS como objeto de análisis del inicio del peloteo es un innovador y nuevo enfoque que se centra en el significado táctico de los golpes que no se expresa en el número de golpes

Palabras clave: *Primer golpe ofensivo, deportes de raqueta, tenis de mesa, análisis de partidos.*

Introduction

After the beginning of the sport in the second half of the 19th century, table tennis has progressed enormously. Not only the International Table Tennis Federation (ITTF) has been growing to the sports federation with the highest number of members in terms of national associations (226), but also the sport itself has been always going through developments in different areas. Due to different rule changes and technological developments, the material of the players developed as well. Big milestones in this area were the invention of the sponge rubber in the 1950s, the invention of the speed glue in the 1970s, the change from 38mm to 40mm ball diameter in 2000, and latest the ban of the speed glue with volatile organic compounds (VOCs) as well as the introduction of the celluloid-free balls in 2014 (Clemett, 2010; Küneth, 2020).

The players did not only adapt their material over the years, but also their way of playing – from changing to a more spin-oriented game style with the invention of the sponge rubber in the 1950s ending up with new shot techniques called “Strawberry” or “Chiquita” in recent years. Until the late 2000s it seemed to be normal to play the short game until the push of one player gets long enough to attack with topspin. But especially since Zhang Jike (World and Olympic Champion) trademarked the sidespin-topspin backhand flip – the so called “Chiquita” – and made it popular, more and more players seem to leave the short game early using this technique which has developed quite fast in recent years (Townsend, 2017). With this specific technique which is used by players not only in backhand side, but also in the forehand side, players can get quite easily out of a rather defensive short game into the offensive game.

This transition from the defensive short game to the offensive attacking game is a very crucial and decisive tactical decision in almost each rally in table tennis: On one hand a player can gain advantage putting the opponent in a defensive position by attacking first, on the other hand, as the first offensive technique in a rally, we call it “first offensive shot” (FOS) is technically difficult and has mostly to be played against a short ball and/or a ball with some backspin played with the intention of not allowing for an offensive shot, the FOS is a risky shot. Besides the risk of a direct error, there is the risk of a FOS of too low quality, so that it can be countered immediately and successfully.

The FOS might be seen as a rewarding technique, if effectively executed, but rather disadvantageous when not being played with high quality. Thus, playing the FOS is a basic tactical decision in almost each table tennis rally (the only exceptions are the very rare serve winners and errors).

On one hand, this is a situational decision of players in the match dependent on the quality of the serve or prior defensive shot, but on the other hand it is also a tactical element of a match strategy for players and coaches to decide whether to go for the FOS or leave it to the opponent. This decision should be supported by match analysis and data collected on the specific opponent.

In this study a new structural model for a table tennis rally including the FOS and develop a corresponding observational system focusing on recording properties of the FOS was introduced. FOS may not be defined based on a shot number in the rally (like serve, receive, third shot, fourth shot etc.), because it is not known a priori which shot will be the FOS. FOSs are semantically similar shots defined as the first shot in a rally without any kind of backspin (serves excluded). Figure 1 shows the process model of a table tennis rally.

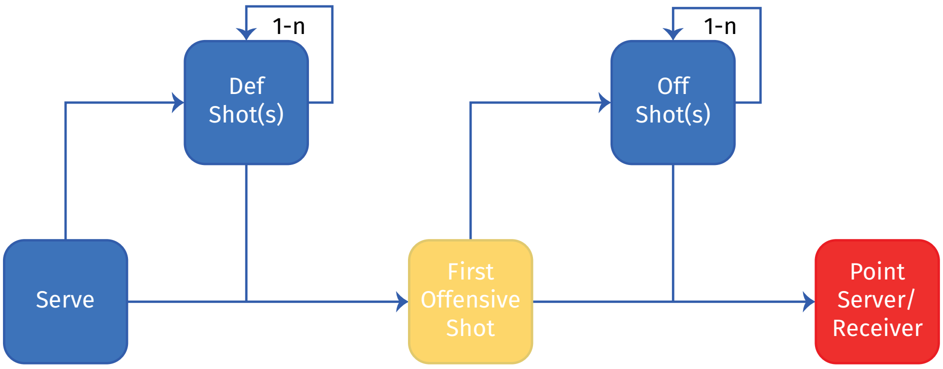

Figure 1. Process model of table tennis rally with first offensive shot.

The model separates the rally in three phases: The first phase consists of serve and defensive shot(s), second and central phase is the FOS, and the third phase contains the following offensive shot(s) until the end of the rally. Accordingly, phase one and three might include a different number of shots in each rally (from 0 to n) and the shot number of the FOS might vary in each rally. The (rare) occasions of point/error with serve or defensive shot are not depicted.

It must be mentioned that this model does not apply to matches with a defensive player as in this case the FOS is most likely followed by defensive shots of the defensive player again and the process would be repeated from phase one within a rally. As only 3% of the current top 100 ranked men and 12% of the current top 100 ranked women in the world ranking are defenders (in January 2021) (International Table Tennis Federation, 2021) these players/matches are neglected in this study.

Different approaches like notational analysis, footwork analysis, performance indices and simulative approaches have been used in table tennis analysis (Fuchs et al., 2018; Malagoli Lanzoni et al., 2014). By analysing existing literature, regardless the approach of the analysis, the FOS has not been addressed in previous table tennis research. Performance analysis in table tennis is typically based on a shot-number based approach, e.g. the three-phase-method in Japan and China, which gives feedback regarding rally length, winning probabilities and error rates of specific shot numbers (Tamaki et al., 2017; Wu & Li, 1992; Zhang et al., 2013). The problem with shot-number based approaches is that the shot number itself doesn't reflect necessarily the semantics or meaning of a shot, e.g. shot #4 may be an all-in attacking forehand topspin shot, a short, defensive backhand push or the first offensive shot in a rally. As a consequence, performance indicators based on shot-number based approaches, e.g. technique effectiveness (Zhang et al., 2013) suffer from this ambiguity. Although this problem has been acknowledged, for example including the techniques used in shot number base approaches, e.g. for shot #1 (serve) and shot #2 (receive) (Djokic et al., 2017; Zhang & Zhou, 2017), the problem remains that semantically similar shots are hard to analyse in these approaches if they have different shot numbers (Zhang & Zhou, 2017).

The aim of this study is to design an observational system to analyse the following characteristics regarding the FOS in a rally in elite table tennis:

- techniques used for FOSs
- position where the FOSs are performed (over vs. behind the table)
- shot number of the FOSs
- serving or receiving players performs the FOS
- differences between men and women and between top ranked and lower ranked players regarding the FOS behaviour?
- winning probability for the FOS player

Methods

First offensive shot (FOS) & prevalent FOS techniques

The FOS in a rally is defined as the first shot after the serve without any kind of backspin/side-backspin. Thus, the serve itself is excluded by this definition, regardless of its spin. Considering the spin condition with the resulting fact that there is either a serve or a defensive backspin/side-backspin shot prior the FOS, possible techniques for the FOS are Flip (including Chiquita), Topspin, Smash, Drive and Special (any other offensive shots which can't be assigned to the other categories) whereas Smash, Drive and Special are summarized as "other" due to their rare use as FOS.

Position relative to table at the point of contact

The position relative to the table at the point of contact is defined as the location where the player hits the ball considering the actual shot movement. In our study we distinguish between two possible positions. The first is "over the table", where techniques need to be adapted because the table poses an environmental constraint (Newell, 1986). The second is "behind the table", where the player hits the ball close to the edge or behind the table and is not restricted in his/her movement range (especially at the backward movement phase of the shot due to the table. Balls hit after going off the side of the table (and not off the back) and are hit on the side with a full backswing are considered as behind the table shots as well.

Independent variables

Two independent variables were used in this study. First, matches of male and female players were compared. Second, using the ITTF world ranking list published on August 1st, 2016 (current ranking lists at the 2016 Olympic games), players were divided into two player categories ("top 50" and "over 50"), resulting in three possible match categories ("top 50 vs. top 50", "top 50 vs. over 50" and "over 50 vs. over 50"). This leads to a two-factor factorial design (sex versus match category).

Data collection and sample

Matches of the 2016 Olympic Games were analysed using video recordings of the International Table Tennis Federation (ITTF)/International Olympic Committee (IOC). By entering the Olympic Games, participants agree to be filmed, televised, photographed, identified and/or otherwise recorded during the Olympic Games, and that their captured or recorded image, together with their name, likeness, voice, performance and biographical information, may be used in any content, format and through any media or technology whether now existing or created in the future (International Olympic Committee, 2016). All data were recorded in an anonymous dataset. Procedures performed in the study were in strict accordance with the Declaration of Helsinki as well as with the ethical standards of the Technical University of Munich, Germany.Matches with players who have a defensive playing style (choppers) and/or use non-attacking rubbers like long pimples were excluded from the sample as they are expected to bias the FOS statistics due to their non-attacking style as mentioned in the previous chapter. 53 different female players (15 left-handed, 38 right-handed; one with one half-long pimple rubber, six with one short pimple rubber, 46 with two backside rubbers) from 34 countries and 48 different male players (twelve left-handed, 36 right-handed; all with two backside rubbers) from 34 countries are included in the sample. All players were using the shakehand grip.

A total of 90 matches were analysed, including 45 men's and 45 women's matches. 15 matches per match category were chosen. Especially matches with "over 50" players were limited as only one woman and four men of this category made it into the round of 16 of the singles competition. Thus, all possible matches of the singles competition with "over 50" players involved were chosen and complemented with matches from the team competition. For the "top50 vs top50" category, matches of the finals and semi-finals of both competitions were analysed and complemented with matches from earlier stages. The 90 analysed matches led to a total number of 7449 analysed rallies, 3889 rallies of men's matches and 3560 rallies of women's matches respectively. Table 1 shows the distribution of matches and rallies according to match categories and sex.

Data analysis and observer agreement

All matches were analysed with the table tennis video analysis tool "TUM.TT" (Lames et al., 2018). For this study only the FOSs were analysed in the deep-analysis-mode of TUM.TT. Therefore, the observer had to identify if there has been a FOS in the rally and mark this shot. For those marked FOSs, the following parameters were collected additionally: Laterality (Forehand (FH)/Backhand (BH)), technique (Flip, Topspin, Smash, Drive and Special) and position relative to table at the point of contact (over/behind the table). Based on the collected variables, three more variables were defined and subject to analyses: FOS by server/receiver, number of shots after FOS and FOS direct impact (yes/no winner/error?).

The inter-observer reliability test calculating an intraclass correlation coefficient (model: two-way mixed, type: absolute, confidence interval=95%) was conducted using a randomly chosen sample of 6 matches (one from each match category) with 517 rallies. These rallies were analysed by two independent observers (one of the authors and a German B-licenced table tennis coach from a Bundesliga club). Reliability was assessed with a two-step approach: First, the identification of the observational unit, i.e. a shot as a FOS in a rally, was tested and resulted in perfect agreement expressed by an intraclass correlation coefficient of 1.000. Second, agreement of assigning levels of the observed variables was tested. The intraclass correlation coefficients for laterality, technique and position relative to table at the point of contact were 1.000, .957 (Lower 95% confidence interval (L95%) at .949) and .940 (L95% = .920) respectively. Thus, for all recorded variables the inter-rater agreement was excellent (Koo & Li, 2016).

Statistical Analysis

IBM SPSS Statistics 25 (IBM Corp., Armonk, New York, USA) was used for the statistical analyses. Descriptive statistics for FOS shot number, laterality-technique-position-combination of the FOS are presented in dependence of sex and match category. The shot number of FOS was tested for normal distribution with the Kolmogorov-Smirnov test and proved violations of normality for FOS shot number (heavily right skewed distribution).

Cross tables and chi-square tests with the Monte Carlo method if necessary were used to identify relations between the independent variables (sex, match category) and the dependent (calculated) variables (FOS laterality, FOS technique, FOS by server/

receiver). For comparison of the FOS shot number between female and male and the match category groups, Mann-Whitney tests and Kruskal-Wallis tests were conducted.

Alpha was set at 0.05 for all analyses. Correlation coefficient r was used as effect size for the Mann Whitney U test as well as for the pairwise comparisons of the Kruskal-Wallis-test in case of significance (Cohen, 1988; Fritz et al., 2012).

Results

From 7449 analysed rallies, 6771 (90.9%) rallies contained a FOS. In 668 (9.0%) rallies there was no FOS because of prior rally termination (serve winner (6.0%), serve error (13.8%), defensive shot winner (17.5%) and defensive shot error (62.7%)). Ten (0.1%) rallies had to be excluded from the sample as the (potential) FOS was not visible in the video footage due to replays or a blocked view.

Four laterality-technique-position combinations (out of twelve) cover 98.3% of all 6771 analysed FOSs. Therefore, we excluded the other eight categories from subsequent analysis. The descriptive statistics of our two-factor factorial model regarding these four laterality-technique-position combinations are shown in Table 2.

The typical FOSs are: Forehand topspin behind the table, forehand flip over the table, backhand topspin behind the table and backhand flip over the table. As topspin is always connected to the behind the table position and flip to the over the table position, we will drop the explicit mentioning of the relative position to the table at time of ball contact in the next sections when talking about topspin and flip. Most used for FOS overall was FH topspin (37.4%), followed by BH topspin (29.3%) and the BH flip (22.3%). FH flip was used least often (10.9%).

A different frequency order for men and women was obtained when analysed separately. FH topspin is still the most used FOS for both men (35.9%) and women (39.1%). But different to the overall order, the second most popular shot for men is the BH flip (27.2%) and not the BH topspin (23.2%). For women, BH topspin (36.1%) is on second place, followed by BH flip (17.0%).

The chi-square test proves a significant relation between sex and the selection of the laterality-technique-position combination for the FOS ($\chi^2(3,N=6654)=264.31, p<.001$).

Table 1.
Data sample: match and rally distribution according to match category and sex.

		Match Category							
		Top50 vs Top50		Top50 vs Over50		Over50 vs Over50		Total	
		Matches	Rallies	Matches	Rallies	Matches	Rallies	Matches	Rallies
Sex	Female	15	1120	15	1081	15	1359	45	3560
	Male	15	1143	15	1294	15	1452	45	3889
	Total	30	2263	30	2375	30	2811	90	7449

Table 2.
Descriptive statistics of FOS laterality-technique-position combination in the two-factor factorial model after excluding marginal shot types.

Sex	Match Category	Forehand				Backhand				Total
		Topspin behind the table		Flip over the table		Topspin behind the table		Flip over the table		
		Count	%	Count	%	Count	%	Count	%	Count
Female	Top50 vs Top50	355	34.9	96	9.4	386	38.0	179	17.6	1016
	Top50 vs Over50	361	37.1	68	7.0	360	37.0	184	18.9	973
	Over50 vs Over50	521	44.2	85	7.2	396	33.6	176	14.9	1178
	Total	1237	39.1	249	7.9	1142	36.1	539	17.0	3167
Male	Top50 vs Top50	383	36.5	159	15.2	238	22.7	268	25.6	1048
	Top50 vs Over50	426	36.6	165	14.2	230	19.8	343	29.5	1164
	Over50 vs Over50	442	34.7	154	12.1	342	26.8	337	26.4	1275
	Total	1251	35.9	478	13.7	810	23.2	948	27.2	3487
Total	Top50 vs Top50	738	35.8	255	12.4	624	30.2	447	21.7	2064
	Top50 vs Over50	787	36.8	233	10.9	590	27.6	527	24.7	2137
	Over50 vs Over50	963	39.3	239	9.7	738	30.1	513	20.9	2453
	Total	2488	37.4	727	10.9	1952	29.3	1487	22.3	6654

Looking at the match categories within each sex, the chi-square tests show a significant relation between the match category and the FOS laterality-technique-position combination for women (χ^2 (6,N=3167)=26.74,p<.001) as well as for men (χ_2 (6,N=3487)=21.86,p=.001). Regarding frequencies, it has to be mentioned that for women in the Top 50 vs. Top50 category BH topspin is most used as FOS, for Top50 vs. Over 50 category FH topspin and BH topspin are more or less equal whilst in the Over50 vs. Over50 category the FH topspin is clearly the most used FOS. For men, in the Over50 vs. Over 50 category the BH topspin is the second most used FOS, whilst for the other categories the BH Flip is on second position (in all men categories FH topspin is the most used FOS).

Regarding the position relative to the table, men intend to open the rally more likely over the table than women (40.9% for men vs. 24.9% for women). The chi-square tests confirmed a significant relation between sex and the position to the table at the point of contact (χ^2 (1,N=6654)=191.68,p<.001). A significant relation is also shown between the match categories and the position relative to the table at the point of contact within each sex (women: χ^2 (2,N=3167)=7.82,p=.020, men: χ^2 (2,N=3487)=6.65,p=.036). For the women's categories a trend towards more over the table FOS was recognizable for the categories with more Top50 players (Over50 vs. Over50: 22.2%, Top50 vs. Over50: 25.9%, Top50 vs. Top50: 27.1%). Within the men's categories the Top50 vs. Over50 (43.6%) had the highest percentage of over the table FOS (Over50 vs. Over50: 38.5%, Top50 vs. Top50: 40.7%).

After describing what was used as a FOS and in which position to the table it was used, the next important point is to get information when in the rally the FOS was used by the players.

A Mann-Whitney-U-Test was calculated to determine if there were differences in the FOS shot number between women and men. The test proved a statistically significant difference in the shot number between women and men (U = 5307059.00 , Z = -2.965 , p = .003 , r = -.036) even though the effect size is very small (Cohen, 1992). The means ($mean_{women}$ = 2.74, $mean_{men}$ = 2.83) and grouped medians ($grouped\ median_{women}$ = 2.64, $grouped\ median_{men}$ = 2.69) show only a very small difference, too.

Figure 2 shows the distribution of the FOS shot number in a rally separated by gender. In both genders the majority of FOSs were performed with the second, third or fourth shot in a rally ($women_{\#FOS}$<=4= 96.9%, $men_{\#FOS}$<=4 = 94.9%).

A Kruskal-Wallis-Tests indicated first that there is a significant difference in the FOS shot number between the different match categories for women (H(2) = 6.729, p = .035), but the post-hoc tests couldn't show any significances. For men no significant difference was found (H(2) = .404, p = .817). This shows that the situations and the moments within a rally when FOS were performed are statistically very similar throughout all male or female match categories respectively, regardless of the FOS player's and the opponent's ranking. Thus, no different tendencies of an earlier or later attacking was found.

By analysing the FOS shot number, we got also the information whether the server (odd shot numbers) or the receiver (even shot numbers) performed the FOS. Figure 3 and Figure 4 show the distribution of the FOS technique for both groups separated for women and men respectively.

In both genders the distribution of the FOSs technique is different whether the server or the receiver performs the FOS. If the server is performing the FOS, topspin (FH+BH) has a much higher percentage than if the receiver is performing the FOS (women: 91.2% topspin (FOS by server) vs. 63.7% topspin (FOS by receiver); men: 74.5% topspin (FOS by server) vs. 49.1% (FOS by receiver)). In men's matches, in case the receiving player is performing the FOS, flip technique (50.9%) is even more often used than the topspin technique. In particular the different use of the BH flip needs to be mentioned. The chi-square tests proved the significant relation between the FOS technique and FOS by serving/ receiving player for men (χ^2 (3,N=3487)=401.21,p<.001), women (χ^2 (3,N=3167)=322.67,p<.001) and overall (χ^2 (3,N=6654)=678.93,p<.001). Thus, it can be said that the FOS behaviour of the receiving player is different from the one of the serving player.

After analysing the distribution and incidences of the different FOS variables, we were interested in the respective rally winning probabilities (wp) for the FOS player. Table 3 shows the incidences of won rallies and winning probabilities for the FOS player in our two-factor factorial model.

For our typical FOSs, the winning probabilities showed clear tendencies. The winning probability for the FOS player was always over 50% when using topspin (FH or BH) as FOS with a minimum of 50.4% in the women's Top50 vs. Top50 category for the FH topspin and 50.4% in the men's Top50 vs. Top50 category for the BH topspin. Using flip as FOS was a disadvantage for the FOS player in two of three categories for men as well as women while executing the flip with FH, and in all categories except the men's Top50 vs. Over 50 category with BH. Table 3 shows that the FH flip is only a "weapon" between two Over50 players as they might not be able to handle the opponents' flip – in contrast to the Top50 players. As the total incidences of the FH flip technique are the lowest among all used techniques, the winning probabilities might also be influenced by the skill of a certain player and probably have greater fluctuation than the winning probabilities of other techniques with greater incidences.

Table 3.
Incidences of won rallies and winning probabilities (in %) for the FOS player for the "typical FOSs" in the two-factor factorial model.

Sex	Match Category	Forehand				Backhand				Total	
		Topspin		Flip		Topspin		Flip			
		behind the table		over the table		behind the table		over the table			
		Count	%	Count	%	Count	%	Count	%	Count	%
Female	Top50 vs Top50	179	50.4	45	46.9	200	51.8	89	49.7	513	50.5
	Top50 vs Over50	211	58.4	24	35.3	190	52.8	77	41.8	502	51.6
	Over50 vs Over50	294	56.4	43	50.6	201	50.8	77	43.8	615	52.2
	Total	684	55.3	112	45.0	591	51.8	243	45.1	1630	51.5
Male	Top50 vs Top50	226	59.0	55	34.6	120	50.4	122	45.5	523	49.9
	Top50 vs Over50	232	54.5	74	44.8	130	56.5	175	51.0	611	52.5
	Over50 vs Over50	259	58.6	79	51.3	193	56.4	164	48.7	695	54.5
	Total	717	57.3	208	43.5	443	54.7	461	48.6	1829	52.5

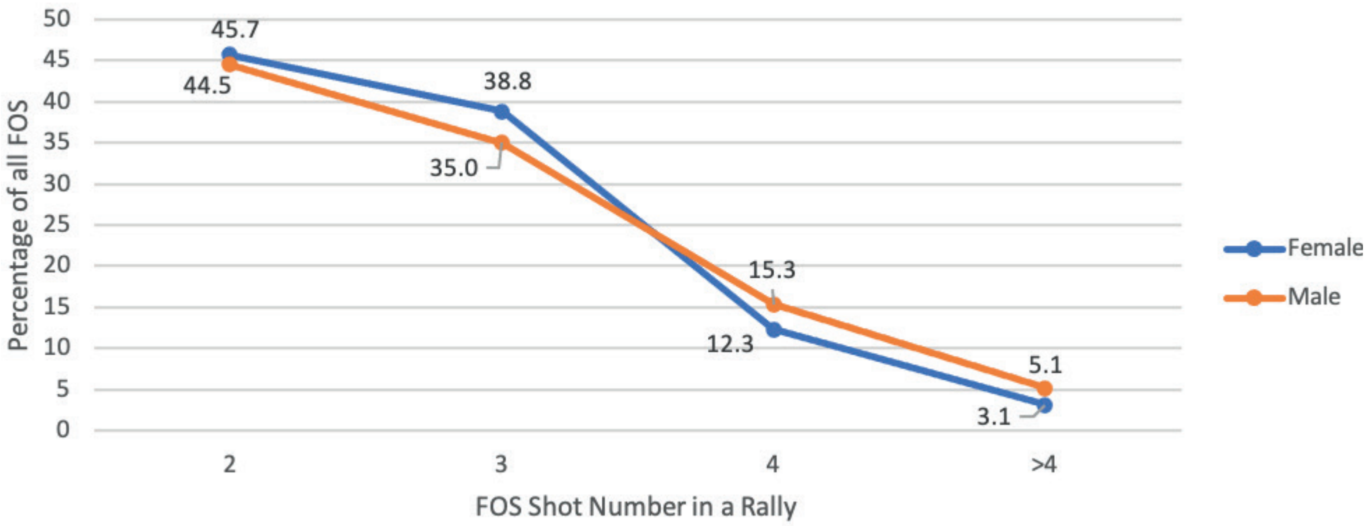

Figure 2. Distribution of the FOS Shot Number in a Rally.

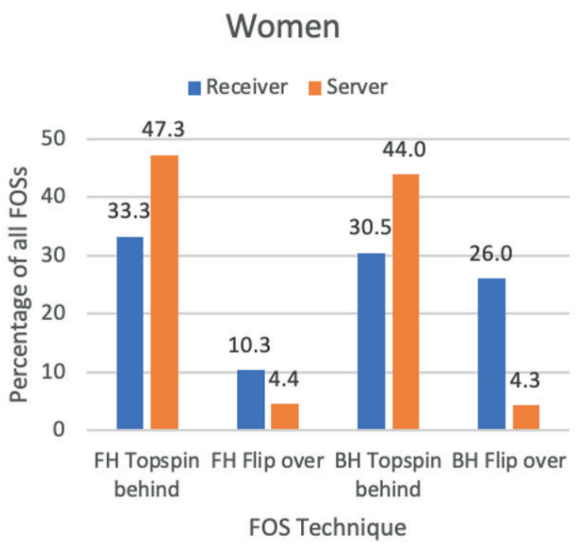

Figure 3. Distribution of FOSs separated by server/receiver for women.

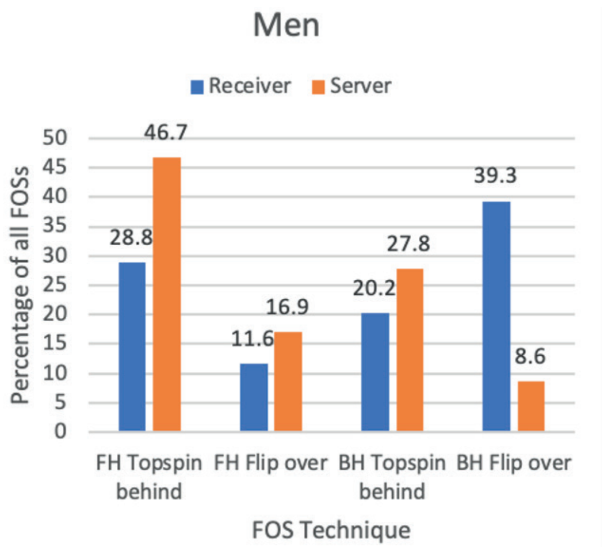

Figure 4. Distribution of FOSs separated by server/receiver for men.

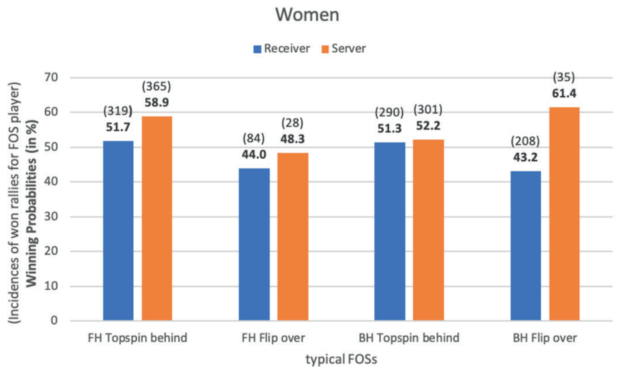

Figure 5. Incidences of won rallies and winning probabilities for the FOS player using the typical FOSs separated by serving or receiving player is performing the FOS for women's matches.

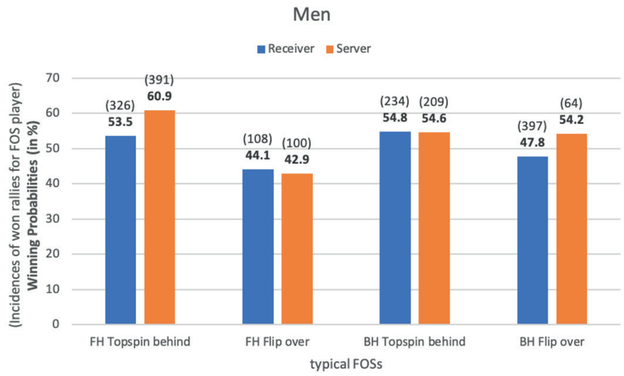

Figure 6. Incidences of won rallies and winning probabilities for the FOS player using the typical FOSs separated by serving or receiving player is performing the FOS for men's matches.

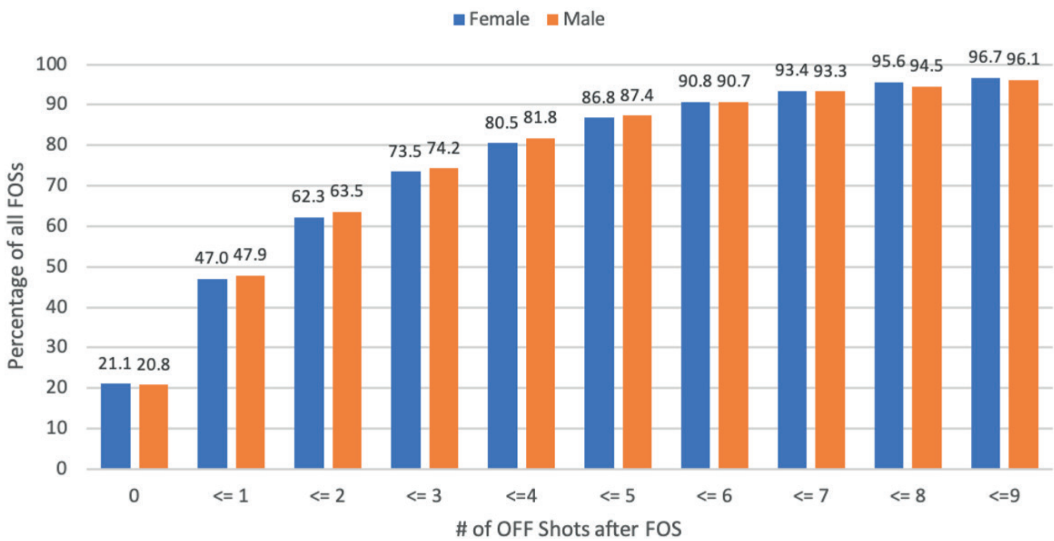

Figure 7. Distribution of the number of offensive shots after the FOS.

Figure 5 (for women) and Figure 6 (for men) show the incidences of won rallies and winning probabilities for the FOS player using the typical FOSs separated by serving or receiving player is performing the FOS.

Topspin with FH or BH as FOS was always an advantage for the server as well as for the receiver. In contrast, using the flip was always a disadvantage except when the server could perform a BH flip as FOS (wp BH $\text{flip}_{\text{mServer}}$ = 54.2%, wp BH $\text{flip}_{\text{wServer}}$ = 61.4%).

The biggest difference in FOS winning probabilities between the serving and receiving player were found for the FH topspin (wp FH $\text{topspin}_{\text{mReceiver}}$ = 53.5% vs. wp FH $\text{topspin}_{\text{mServer}}$ = 60.9%, wp FH $\text{topspin}_{\text{wReceiver}}$ = 51.7% vs. wp FH $\text{topspin}_{\text{wServer}}$ = 58.9%) and the BH flip (wp BH $\text{flip}_{\text{mReceiver}}$ = 47.8% vs. wp BH $\text{flip}_{\text{mServer}}$ = 54.2%, wp BH $\text{flip}_{\text{wReceiver}}$ = 43.2% vs. wp BH $\text{flip}_{\text{wServer}}$ = 61.4%) in both genders with the higher winning probabilities for the serving player.

The FOS is arguably a crucial moment in a rally, but the advantage/disadvantage by performing the FOS might be neutralized in longer rallies. Figure 7 shows the distribution of the number of offensive shots after the FOS in a rally.

Over 60% of all rallies (women: 62.3%; men: 63.5%) are finished with a maximum of two offensive shots after the FOS, and almost three quarters are finished with three or less shots after the FOS (women: 73.5%; men: 74.2%).

To get a better indication of the direct impact of the FOS, the sample was additionally split into two subsamples. The upper limit for the direct impact of the FOS was derived by an inspiration of the first phase of the Three-Phase-Model approach (Wu & Li, 1992) with the FOS as starting point. As direct impact we defined rallies which finished latest with the follow up attack after the FOS of the FOS player (including a possible mistake of the opponent with the following shot) which leads to the first, the "direct impact of FOS" subsample. The second ("no direct impact of FOS") subsample includes all remaining rallies with more offensive shots after the FOS. Figure 8 and Figure 9 show the incidences of rallies with a direct impact or no direct impact of the respective FOSs. The figures show the same trend, regardless of the used FOS. More rallies are finished with a direct impact of the respective FOS.

When talking about the intention the FOS player should have, Figure 10 and Figure 11 are clearly showing that it was more successful for the FOS player if a rally was finished with a direct impact of the FOS. Only the rallies in women's matches with FH flip as FOS showed a higher winning probability for the FOS player in the longer rallies compared to the "direct impact of FOS" rallies (wp FH $flip_{wDirectImpact}$ = 44.1% vs. wp FH $flip_{wNoDirectImpact}$= 47.6%).

Discussion

This study aimed to give a better understanding of the FOS in a rally in top level table tennis. For that purpose, FOS shot number, FOS laterality, FOS technique and FOS position towards the table at the point of contact have been analysed while taking into account the influence of sex and the respective player/match category. Additionally, the winning probabilities for the FOS player have been analysed. The inter-observer reliability tests for all variables showed excellent inter-rater agreements. For the identification of the FOS and the laterality of the FOS an almost perfect agreement was expected as the differences between defensive and offensive shots and FH/BH can be identified easily. Although assigning the levels of the other observed variables for the FOS (technique and position) is not trivial, still a high agreement between experienced coaches was expected as only very few situations, e.g. short BH topspin movements vs. BH flip after a half-long ball, might result in different value assignments. But in most cases, the techniques and the position relative to the table is clearly recognizable by (experienced) observers.

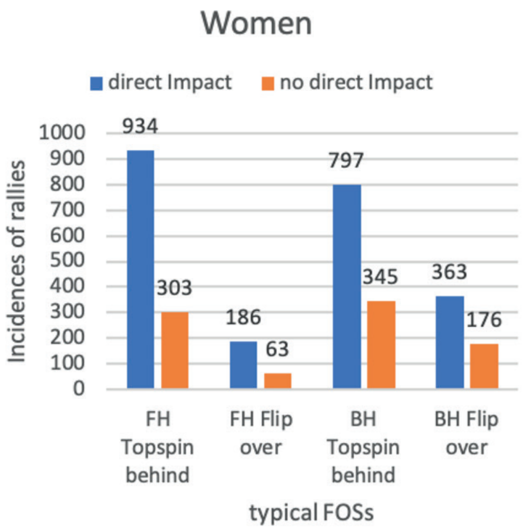

Figure 8. Incidences of typical FOSs separated by impact of FOS for women.

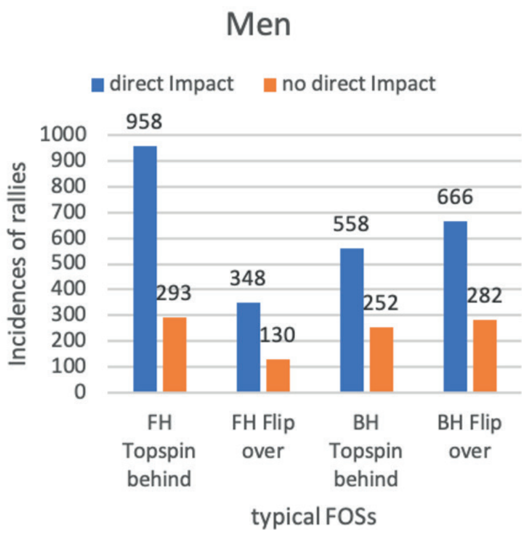

Figure 9. Incidences of typical FOSs separated by impact of FOS for men.

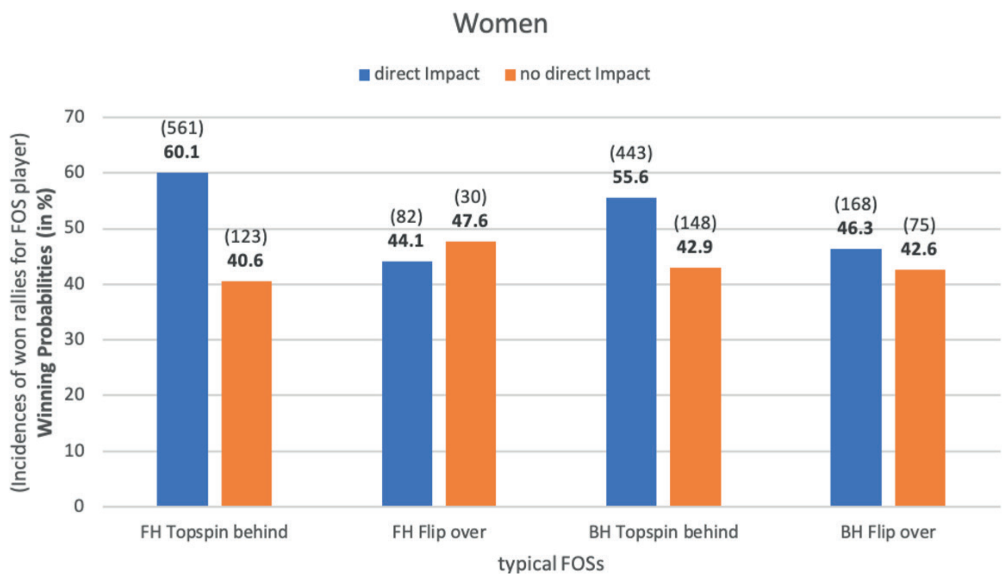

Figure 10. Incidences of won rallies and winning probabilities for the FOS player using the typical FOSs separated by direct or no direct impact of the FOS for women's matches.

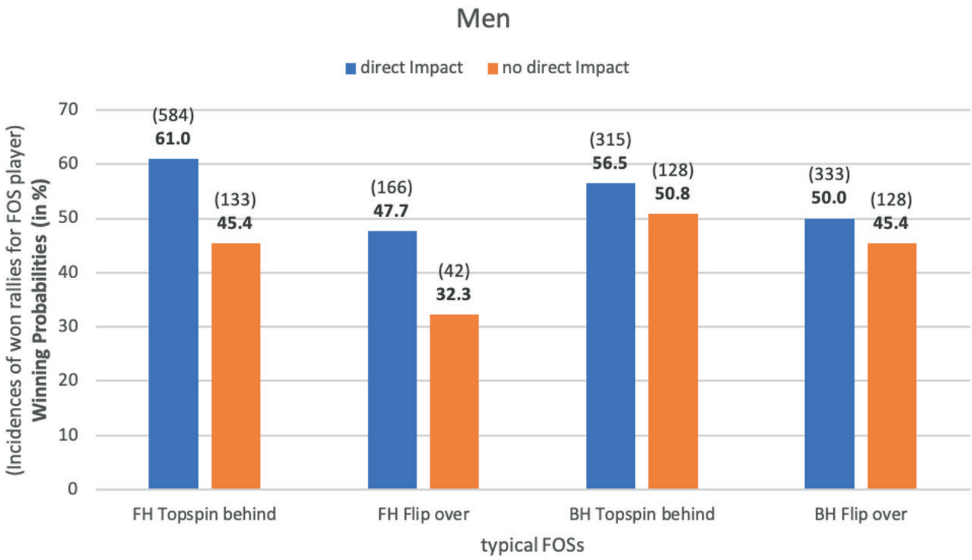

Figure 11. Incidences of won rallies and winning probabilities for the FOS player using the typical FOSs separated by direct or no direct impact of the FOS for men's matches.

The results of this study revealed that there are four typical FOSs covering 98% of all FOSs. The women's more frequent use of backhand as FOS might be caused by the fast and close to the table (and because of that often more backhand oriented) playing style of women compared to men.

The FH topspin is the most used FOS in all men's match categories and in two of three women's categories. Only in the women's Top50 vs. Top50 category the BH topspin is more often used than the FH topspin. Overall, female players prefer the topspin technique (FH and BH topspin clearly on first and second place covering together more than 73% of FOSs in all categories) over the flip technique. The flip technique is more often used in men's compared to women's matches leading to a significantly different distribution of the techniques between men and women. Especially the more frequent use of the backhand flip in the men's matches (which is tantamount to more over the table FOS) is probably explained by a different serve and receive game in the different genders. Men are more likely serving short – which is confirmed by the study of Djokic et al. (2020) – to avoid a direct full swing topspin of the opponent whilst – following Zhang and Zhou (2017)– women don't seem to be afraid to serve or push with the receive more frequently half long or long because the opponents opening topspin can be controlled or even countered. This might be based on differences in physical capabilities between men and women which lead to a possibly stronger FOS topspin in the men's game which opponents are afraid of.

A similar average FOS number for men and women (grouped $median_{women}$ = 2.64, grouped $median_{men}$ = 2.69) with the different FOS behaviour explained before supports the explanation that the FOS might be highly affected or rather controlled by the serve as not too much short-short game is going on for both genders. To prove this hypothesis, additional research on the shot(s) prior to the FOS needs to be done.

The different FOS behaviour between server and receiver might also be explained by the receiving game of the majority of players, especially for men. The popularity of the BH banana flip directly as receive might be one reason. The difficulty to receive really short a second one. It seems that if the receiver doesn't attack directly, but plays a defensive push, the server can (or needs to) attack that push very often with a topspin. This can happen due to a failed short push which went half long or long but also due to the conscious decision to receive with an aggressive long push. The second option seems to get more and more popular. With a controlled long push, the receiver provokes a topspin with more spin from behind the table, which might also be easier to control. The attempt to push short involves always the risk of a qualitatively bad or too high short ball which can be easier killed than a long push loaded with backspin.

Regarding the winning probabilities, explanations for certain results are very hard to give as so many factors come into play. Noticeable is that the winning probabilities for topspin techniques as FOS were always >50% and always bigger than the winning probabilities for the flips.

Using the flip as FOS was a disadvantage for the FOS player in nine out of twelve cases (Table 3). Only the FH flip in the women's and men's Over50 vs Over50, as well as the BH flip in the men's Top50 vs Over50 category showed winning probabilities >50%. There may be diverse reasons why the flip as FOS is not an advantage. For example, in the male Top50 vs Top50 category (wpFH flip = 34.6%), the non-FOS player might be able to counter the flip with high quality. The flip technique itself might be the problem in that category as it is simply not strong enough in terms of spin (opponent can control the top-/sidespin) and speed (opponent is fast enough and has very good anticipation) which might be different in categories with lower ranked players involved.

Although it can be stated that topspin is the more successful FOS than flip, exclusively using topspin as FOS is not an option. Using flip (especially as a receiver) might be highly influenced by the opponent's serve which might give no possibility to topspin and at the same time makes it very difficult to play a good short ball. Thus, players are almost forced to play a flip in those situations.

Following the analysis of the post FOS shot number and the respective winning probabilities, the intention for the FOS should be to finish the rally with his/her follow up shot. Especially when using topspin as FOS, the winning probabilities for the FOS player were way higher in the rallies finished quickly after the FOS compared to the longer rallies. This means, when opening the rally with a topspin, the FOS player should try to kill the ball with his/her next shot at the latest. Otherwise, the advantage will decrease noticeably (decrease for women matches at 19.5% (FH topspin) and 12.7% (BH topspin), decrease for men's matches at 15.6% (FH topspin) and 5.7% (BH topspin)). For the flip as FOS, no clear trend could be found (big decrease for FH flip in men's matches, but even an increase for FH flip in women's matches; decreases for BH flip <5% for both genders). Thus, no general advice for the tactical behaviour after the flip as FOS can be given based on the study's results as it seems to be a more individual consideration whether and when the FOS player is successful with the flip as FOS.

Following the findings of our study, some practical suggestions for players and coaches can be given: As flip was a disadvantage and topspin was an advantage overall, the importance of a good quality short push instead of opening the rally with a flip should be taken into account in the daily work. Closing the rally with the follow up attack after a player could take the initiative with a topspin is a second important finding for players and coaches not only for competitions, but also in the design of competition-like exercises in training.

Some limitations of the study need to be acknowledged. First, the FOS behaviour and the FOS winning probabilities are highly influenced by the placement and quality of the shot prior to the FOS which is not analysed in this study. This information could help to identify e.g. after which placement certain FOSs are (successfully) performed. Second, the world rankings of the players - especially in first round matches including wild card players – show larger variance. Thus, although players belong to the same player category, there might be a difference in the level of skills which might have an influence on the FOS behaviour especially on the winning probabilities of certain techniques.

Despite these limitations, the conceptual advantages of the introduced process model for a table tennis rally could be clearly shown. Tactical behaviour for the first offensive shot could be analysed without any dependency on a specific shot number. The results for the FOS number underlined the necessity of such a shot-number-independent approach as the FOS number was spread over a range of shot numbers. Moreover, ambiguities in shot-number-based approaches – a third shot may be a defensive short push as well as an all-in attacking shot – speak as well in favour of the presented, shot number independent FOS analysis.

Conclusion

This study provides a first overview of the FOS behaviour in elite table tennis using a new shot-number-independent approach. The detailed technical/tactical analyses of the FOS behaviour, including the analysis of the winning probabilities gives more precise knowledge about the structure of the sport. The reliable information about different FOS behaviour for men and women or for the serving and receiving player respectively, the differences between match categories and the differences of winning probabilities could lead to practical implications for training and competition and also to adaptions in the tactical education in the development of (young) athletes.

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References

Clemett, C. (2010). Evolution of the Laws of Table Tennis and the Regulations for International Competitions [PDF file]. Retrieved April 27, 2020, from https://www.ittf.com/wp-content/uploads/2016/10/ColinEvolution.pdf

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. L. Erlbaum Associates.

Cohen, J. (1992, Jul). A power primer. *Psychol Bull*, 112(1), 155-159. https://doi.org/10.1037//0033-2909.112.1.155

Djokic, Z., Malagoli Lanzoni, I., Katsikadelis, M., & Straub, G. (2020, 06/30). Serve analyses of elite European table tennis matches. *International Journal of Racket Sports Science*, 2(1). https://journal.racketsportscience.org/index.php/ijrss/article/view/22

Djokic, Z., Munivrana, G., & Levajac, D. (2017). Match analyses of final game of Men's Team European Championships 2014 - Portugal vs. Germany. In M. Kondric, X. Zhang, & D. Xiao (Eds.), *Science and Racket Sports V* (pp. 113-121). Soochow University Press.

Fritz, C. O., Morris, P. E., & Richler, J. J. (2012, Feb). Effect size estimates: current use, calculations, and interpretation. *J Exp Psychol Gen*, 141(1), 2-18. https://doi.org/10.1037/a0024338

Fuchs, M., Liu, R., Malagoli Lanzoni, I., Munivrana, G., Straub, G., Tamaki, S., Yoshida, K., Zhang, H., & Lames, M. (2018, Dec). Table tennis match analysis: a review. *Journal of Sports Sciences*, 36(23), 2653-2662. https://doi.org/10.1080/02640414.2018.1450073

International Olympic Committee. (2016). *Conditions of Participation - National Olympic Committee - Rio 2016*. Retrieved 14th January from http://naaz.co.zw/Portals/0/PropertyAgent/458/Files/164/Rio%202016_Conditions%20of%20Participation_National%20Olympic%20Committee.pdf

International Table Tennis Federation. (2021). *2021 ITTF Table Tennis World Ranking*. Retrieved 14th January from https://www.ittf.com/2021-ittf-table-tennis-world-ranking/

Koo, T. K., & Li, M. Y. (2016, Jun). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med*, 15(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Küneth, T. (2020). *The transition from celluloid to plastic balls*. International Table Tennis Federation. Retrieved April 27 from https://www.ittf.com/2020/01/28/transition-celluloid-plastic-balls/

Lames, M., Fuchs, M., & Wenninger, S. (2018). Wettkampfdiagnostik im Tischtennis. In *BISp-Jahrbuch : Forschungsförderung 2016/17* (pp. 85-91). https://www.bisp.de/SharedDocs/Downloads/Publikationen/Jahrbuch/Jahrbuch_2016_2017_Gesamt.pdf?__blob=publicationFile&v=2, http://my.page2flip.de/2895682/14185088/14185117/html5.html#/86

Malagoli Lanzoni, I., Di Michele, R., & Merni, F. (2014). A notational analysis of shot characteristics in top-level table tennis players. *European Journal of Sport Science*, 14(4), 309-317. http://search.ebscohost.com/login.aspx?direct=true&db=sph&AN=95861706&site=ehost-live

Newell, K. M. (1986). Constraints on the Development of Coordination. In N. G. Wade & H. T. Whiting (Eds.), *Motor Development in Children: Aspects of Coordination and Control* (pp. 341-360). Matinus Nijhoff, Dordrecht.

Tamaki, S., Yoshida, K., & Yamada, K. (2017, Jan 01). A Shot Number Based Approach to Performance Analysis in Table Tennis. *J Hum Kinet*, 55, 7-18. https://doi.org/10.1515/hukin-2017-0002

Townsend, W. (2017). *Tutti frutti table tennis terminology*. International Table Tennis Federation. Retrieved April 27 from https://www.ittf.com/2017/09/10/tutti-frutti-table-tennis-terminology/

Wu, H., & Li, Z. (1992). Research on technical diagnosis method for table tennis players. *International Journal of Table Tennis Sciences*, 1, 99-103.

Zhang, H., Liu, W., Hu, J. J., & Liu, R. (2013). Evaluation of elite table tennis players' technique effectiveness. *Journal of Sports Sciences*, 31(14), 1526-1534. http://search.ebscohost.com/login.aspx?direct=true&db=sph&AN=90464904&site=ehost-live

Zhang, H., & Zhou, Z. (2017, 2017/11/02). An analytical model of the two basic situation strategies in table tennis. *International Journal of Performance Analysis in Sport*, 17(6), 970-985. https://doi.org/10.1080/24748668.2017.1415071

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Original article

Are Technical and Timing Components in Para-Badminton Classifications Different?

¿Son diferentes los componentes técnicos y de tiempo en las clasificaciones de parabádminton?

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Abstract

Considering the smaller number of studies investigating Para-Badminton (PBd) and the need to understand the technical, tactical and functional classes, the purpose of this research is to investigate the frequency of technical components and timing characteristics in the PBd categories of WH1(Wheelchair/severe impairment) and WH2 (Wheelchair/minor impairment) and to compare between classes. Twenty PBd matches were analyzed in the men's individual category at the 11th World PBd Championship. The mean playing time of the matches was 1,780 (± 575) s for the WH1 class and 2,012 (± 1,098) s for WH2. The average rally time was 10.2 (± 8.4) min for the WH1 and 12.5 (± 12.5) min for WH2. The mean pause time was 15 (± 10.3) s for the WH1 class and 14.1 (±10.5) s for the WH2. The mean number of shots per game was 552 (±197) and 719 (±480) for class WH1 and WH2 respectively. In both classes: the most frequent shots performed by the players were Clear, Lob, Drop, and Net-shot; the players used backhand more often than the forehand service and the short service compared to the long one; the errors stood out in relation to the winner points. In addition, there was a higher proportion of shots at the front of the court in both classes. It was found that the WH2 class showed a higher intensity (longer rally time and shorter pause time) and a higher frequency of technical actions (higher number of shuttle hits) when compared to the WH1. This information can assist coaches during training to guide the development of the temporal and technical aspects of the PBd, as well as monitor them during matches to obtain victory.

Keywords: *Paralympic sport; notational analysis; Para-Badminton; physical disabilities.*

Resumen

Teniendo en cuenta la reducida cantidad de estudios con el parabádminton (PBd) y la necesidad de entender las clases técnicas, tácticas y funcionales, el objetivo de esta investigación es indagar la frecuencia de los componentes técnicos y las características de tiempo en las categorías WH1 (silla de ruedas/discapacidad severa) y WH2 (silla de

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ruedas/discapacidad menor) de PBd, así como comparar dichos datos entre clases. Se analizaron veinte partidos de PBd en la categoría individual masculina en el 11° Campeonato Mundial de PBd. El tiempo medio de juego de los partidos fue de 1780 segundos (SD = 575) para la clase WH1 y 2012 segundos (SD = 1098) para WH2. El tiempo promedio de peloteo fue de 10,2 minutos (SD = 8,4) para WH1 y 12,5 (SD = 12,5) para WH2. El promedio relacionado con el tiempo de pausa fue de 15 segundos (SD = 10,3) para la clase WH1 y 14,1 (SD = 10,5) para la WH2. El número medio obtenido de golpes en el volante por partido fue de 552 (SD = 197) y 719 (SD = 480) para la clase WH1 y WH2, respectivamente. En ambas clases, los golpes más frecuentes realizados por los jugadores fueron *Clear, Lob, Drop y Net-shot*; los jugadores utilizaron más el servicio de revés que el de derecha y el servicio corto en comparación con el largo; los errores se destacaron en relación con los puntos ganadores. Además de esto, hubo una mayor proporción de golpes en la parte delantera de la cancha en ambas clases. Se encontró que la clase WH2 mostró mayor intensidad (mayor tiempo de peloteo y menor tiempo de pausa) y mayor frecuencia de acciones técnicas (mayor número de golpes en el volante) en comparación con la WH1. Esta información puede ayudar a los entrenadores para orientar el desarrollo de los aspectos temporales y técnicos del PBd, así como a monitorearlos durante los partidos para obtener la victoria.

Palabras clave: *Deporte paralímpico, análisis notacional, parabádminton, discapacidades físicas.*

Introduction

Para-Badminton (PBd) is a sport that is on the rise worldwide and presents itself with a promising future following its inclusion in the Paralympic Games (IPC, 2014). PBd is a racket sport with individual or doubles matches across five events: men's and women's singles, men's and women's doubles, and mixed doubles, each requiring specific preparation in terms of technique, control, and physical fitness. Besides, the basic rules of the sport have adaptations to the playing court and additional equipment, under the players' classification and event (BWF, 2020).

The classification systems aim to ensure that para-athletes achieve sporting excellence regardless of their disability (Tweedy & Vanlandewijck, 2011; Ungerer, 2018). Each Paralympic sport determines its functional classification system for physical disabilities (Beckman, Connick & Tweedy, 2017). This system is based on functional skills and specific assessments that allocate para-athletes to specific sports classes (Ungerer, 2018) to warrant fairness in the competition (Tweedy, Mann & Vanlandewijck, 2016; Tweedy & Vanlandewijck, 2011). Based on these assessments, there are six classifications in PBd: WH1 and WH2 for wheelchair users; SL3, SL4, and SU5 for ambulant players; SH6 for short stature (BWF, 2020). Specifically, the types of disabilities eligible to participate in PBd include decreased muscle strength, decreased range of motion, athetosis, hypertonia, ataxia, limb deficiency, differences in limb length and short stature (BWF, 2020).

Regarding sports performance, it becomes common in conventional Badminton, analysis of matches components, and indicators of performance success (Chiminazzo et al., 2017; Chiminazzo et al., 2018). The quantification of strokes performed during matches provides useful information to establish performance-specific training prescription parameters (Fernandez-Fernandez, Sanz-Rivas & Mendez-Villanueva, 2009). Notational analysis provides an objective assessment of an individual's performance through the analysis of selected variables, therefore providing useful feedback for coaches and players to improve performance (Phomsoupha & Laffaye, 2015).

While there are some studies exploring PBd in the literature, these are comparatively few compared to conventional Badminton (Strapasson, et al., 2017; Strapasson et al., 2018). Although the structure of PBd is similar to Badminton, issues related to functional classes must be investigated to ensure the principle of fairness in the competition (Tweedy et al., 2016). These classification systems group athletes into classes to minimize the impact of disability on the outcome of the competition (Tweedy et al., 2016; Tweedy & Vanlandewijck, 2011). The literature has indicated that functional classes are factors that differentiate sports performance in training or competition contexts (Antunes et al., 2017; Burkett et al., 2018; Rhodes, Mason, Malone & Goosey-Tolfrey, 2015). Despite this, discussions regarding sports classes, functionality, and performance potential are still constant in different Paralympic modalities (Antunes et al., 2017; Burkett et al., 2018; Tweedy et al., 2016; Tweedy & Vanlandewijck, 2011; Ungerer, 2018).

Considering the lack of studies with PBd athletes (Strapasson et al., 2017; Strapasson et al., 2018) and the need to understand the technical, tactical and functional classes of the sport, the purpose of this research was to investigate the frequency of technical components and timing characteristics in categories WH1 and WH2 of PBd, and to compare between classes.

Materials and Methodology

From a total sample of 58 players (n = 33 WH1 - Wheelchair / severe impairment; n = 25 WH2 - Wheelchair / minor impairment), 20 PBd matches from the men's singles category at the 11th World PBd Championship held in Ulsan, South Korea, in 2017 were randomly selected for analysis. The analysed games involved 28 players in the WH1 and 14 players in WH2 categories; performance was coded from the group phase to the finals. The matches were recorded using three camcorders (JVC® brand), installed on tripods positioned in the cabin reserved for television professionals, thus providing coverage of the entire playing court. Subsequently, the matches were watched and analyzed by one of the researchers who transcribed the data to a spreadsheet in Microsoft Excel® 2016. It should be emphasized that a single evaluator was responsible for recording the data, thus avoiding the variability of information and the adoption of different technical criteria.

One match was randomly selected to be analyzed on two separate occasions by the same evaluator. There was an interval of 10 days between the analysis so that the observation was not influenced by the memory of previous observations when recording the different game situations. This process allowed the determination of intra-observer reliability. The intra-class correlation coefficient (ICC - mixed bidirectional effects, consistency) was used to test the reliability between rally-time observations, the number of shots and pause time. The ICC results (ICC3.1 = 1.00; CI95% = 0.99 to 1.00; p < 0.001) indicated reliable values for game observations (Landis & Koch, 1977).

Variables Analyzed

For the analysis of temporal aspects, the match duration, the duration of rallies, the pause time, and the number of shots per rally were verified. The occurrence of the following technical actions of the game: Service, Clear, Smash, Lob/Lift, Net-shot, Drop and Drive, Winners Points (WP), Forced Errors (FE) and Unforced Errors (UE) were also recorded for the analysis of spatial aspects, the sectors of the court were divided into two zones (Front and Back), to indicate the areas on the court where the winning point shuttle fell most frequently.

Data Analysis

Descriptive statistics composed of mean, standard deviation (SD), confidence interval (95%CI) and frequency distribution (absolute and relative) were used to summarize the data. The Cohen's effect size (ES) (d - continuous data, w - for chi² test, odds ratio - data frequency) and percent delta (Δ%) were calculated to examine the differences between variables.

The Kolmogorov-Smirnov test demonstrated that the variables did not exhibit normal distribution (rally time: K-S = 0.164; p < 0.001; number of shots: K-S = 0.177; p < 0.001 and pause time: K-S = 0.164249; p < 0.001). The Mann-Whitney U test was used to compare rally time, the number of shots, and the pause time between WH1 and WH2 classes. The comparison of number of shot between WH1 and WH2 was performed using the chi² test (χ^2). The effect size Cohen's was used for quantifies the magnitude of the difference in means (*D*) and in chi-square test (*w*).We used a value of α = 5% to identify significant differences between classes.

Results

The mean playing time of the matches was 1,780 (± 575) s for the WH1 class and 2,012 (± 1098) s for WH2. Table 1 presents the results for the duration of rallies, shots and pause time for PBd matches. Table 1 presents the descriptive results and comparison between WH1 vs. WH2 Classes.

Table 1.
Descriptive results and comparison between WH1 vs WH2 Classes.

	Rally Time (min)		Shots (#)		Pause Time (s)	
	WH1	WH2	WH1	WH2	WH1	WH2
Mean (SD)	10.2 (8.4)	12.5 (12.5)	8.0 (7.0)	10.0 (10.0)	15.0 (10.3)	14.1 (10.5)
CI95%	9.5 to 10.9	11.6 to 13.4	8 to 9	9 to 11	14.2 to 15.8	13.3 to 14.9
D	0.2 (small; -0.4 to -0.03)		0.3 (small; -0.4 to -0.04)		0.1 (trivial; -0.1 to 0.3)	
Δ%	23.0 %		27%		-6%	
M-W test	Z = -1.942, p = 0.05		Z = -3.064, p = 0.002		Z = -5.835, p < 0.001	

Legend: CI95% = 95% confidence interval; D = Cohen's effect size; Δ% = percent of change; M-W test: Mann-Whitney U test.

The mean number of shots per game obtained was 552 (±197) and 719 (±480) for class WH1 and WH2, respectively. The WH2 players showed a higher frequency of technical actions (*p* < 0.001; effect size *w* = 0.3 to 1.3; medium to large), in Drive (*w* = 1.3; large) and Smash (*w* = 0.8; large) and in short forehand and backhand services (*w* = 0.6; large). Table 2 shows that the most frequent shots performed by the players in both classes, Clear, Lob, Drop, and Net-shot.

The association between from the points coming from winners, unforced errors and unforced errors these variables was not significant (χ^2 = 0.89; p = 0.64; w = 0.1 - small).

There was a higher proportion of shots at the front of the court in both classes. The chi-square test was conducted to examine the relationship between functional classes and the region of the court where most winners occurred. The association between these variables was non-significant (χ^2 = 1.41; p = 0.23; w = 0.1 - small).

Table 2.
Absolute and relative frequency of shots performed by players.

Shots	WH1 n (%)	WH2 n (%)	Chi-square test (effect size w, category)
Clear	1982 (43%)	2635 (57%)	χ^2 = 92.35, p < 0.001* (w = 0.3; medium)
Drive	23 (23%)	79 (77%)	χ^2 = 30.74, p < 0.001* (w = 1.3; large)
Drop	737 (40%)	1102 (60%)	χ^2 = 72.44, p < 0.001* (w = 0.4; medium)
Lob	870 (37%)	1463 (63%)	χ^2 = 150.73, p < 0.001* (w = 0.5; large)
Net-shot	525 (37%)	903 (63%)	χ^2 = 100.06, p < 0.001* (w = 0.5; large)
Short Forehand Service	146 (43%)	197 (57%)	χ^2 = 16.71, p < 0.001* (w = 0.5; large)
Long Forehand Service	118 (65%)	63 (35%)	χ^2 = 16.71, p < 0.001* (w = 0.6; large)
Short Backhand Service	200 (37%)	336 (63%)	χ^2 = 34.50, p < 0.001* (w = 0.5; large)
Long Backhand Service	150 (56%)	116 (44%)	χ^2 = 4.34, p < 0.037* (w = 0.3, medium)
Smash	128 (31%)	281 (69%)	χ^2 = 57.23, p < 0.001* (w = 0.8; large)
Total	4879 (40%)	7175 (60%)	χ^2 = 437.30, p < 0.001* (w = 0.4; medium)

Legend: Small, medium and large effect sizes as defined by Cohen (1988).

Discussion

The result of this research shows that in the WH2 classification matches, the rallies last longer, players have more shots, and the pause time between games was shorter compared to the WH1 class. It is possible that these differences occurred due to the characteristics of both classifications. The PBd players allocated to the WH2 class present impairment in one or both lower limbs and minimal or non-existent impairment of the trunk whereas, WH1 class players have a greater motor impairment, especially in the lower limbs and trunk function (Latino, Cassese & Tafuri, 2018). The more pronounced impairment of the trunk function that affects WH1 class players influences the movement speed on the court (Haydon, Pinder, Grimshaw & Robertson, 2018) and it may be associated with the fact that they had fewer hits, less rally time, as well as taking more time to retrieve the shuttle from the floor increasing the pause time. Thus, it appears that the motor limitation of WH1 players directly impacts the match dynamics.

Despite the statistical differences in "number of shots" and "pause time" between classes, this result should be observed with caution. The comparison between these variables was small and trivial, which indicates the need for further investigations to avoid overvaluing the observed differences.

The findings in this study indicate a greater match volume in WH2 class matches due to an increased number of shots, longer average rally time, and shorter pause time when compared to the WH1 class. In this way, it is possible to affirm that the intensity in the WH2 class matches may be associated with the greater mobility capacity of players in this class (Strapasson et al., 2017).

Additionally, players of the WH2 class showed a higher frequency of technical actions in "Drives" and "Smashes" compared to the WH1 class. The "Drive" is one of the fastest shots in Badminton and commonly used in doubles matches (Cabello-Manrique & Gonzalez-Badillo, 2003). The superior trunk control and stability of the WH2 class players, as well as faster reaction speeds and movements with the wheelchair (Rietveld et al., 2019), may explain the greater use of the "Drive" in this class compared to WH1.

In the case of the Smash, the WH2 class players showed a higher frequency of executing this shot when compared to the WH1 class players. The "Smash" is a strike on the shuttle that is executed above the headline and with a descending trajectory at maximum speed, aiming to hit the floor as quickly as possible (Strapasson et al., 2017). The results confirmed that the use of a Smash by a player in a wheelchair depends directly on the level of motor impairment. An indication of this was that WH2 class players showed greater use of this shot compared to WH1 class players, mainly due to the greater impairment of WH1 players' trunk function (Latino et al., 2018).

As for services, players of both classes used backhand more often than the forehand service and the short service compared to the long one. Varying the types of services cause unpredictability and makes it difficult for the opponent to return them (Phomsoupha & Laffaye, 2015). The WH2 class players prefer to use short backhand and forehand services, while the WH1 class has a preference for long services (forehand and/or backhand). Additionally, in PBd, the backhand service is more commonly used and is associated with stability due to a minimization of trunk imbalance. The backhand service is performed with two arms close to the body without requiring high levels of joint amplitudes. In this way, this would be a tactical indication for matches in which the opponent has a decrease in passive range of movement and hypertonia, eligible conditions for PBd players. In this sense, world-class players prefer to serve short to prevent their opponents from gaining an offensive advantage (Fernandez-Fernandez et al., 2009; Phomsoupha & Laffaye, 2015).

Another observation resulting from this study is related to the higher frequency of unforced errors in both classes, signaling a lack of consistency in the match, which leads them to make many mistakes during the game. One of the characteristics of Badminton is the accuracy; therefore, players who make fewer mistakes are more likely to win a match (Abian-Vicent, Castanedo, Abian & Sampedro, 2013; Chiminazzo et al., 2017; Cabello-Manrique & Gonzalez-Badillo, 2003). These results suggest that the consistency of shots and winner points are a decisive factor towards the final result. These results are repeated in each sport class.

In relation to the region of the court where most winning points occurred, the front was the most frequent in both classes. The area at the front of the court is the most vulnerable part, and it relates to the offensive game strategy (Phomsoupha & Laffaye, 2015; Strapasson et al., 2017; Ribeiro & Almeida, 2020). The decision to use this strategy in PBd can be explained by the difficulty in reaching the shuttle due to the sitting position and the players' trunk flexion difficulties, common in wheelchair players (Beckman et al., 2017; Zemková, Muyor & Jeleň, 2018).

Despite the small number of matches analyzed, the results of this research provided additional knowledge about the sport, in view of the limitation in the number of publications relating to PBd. New and further studies, to verify the other PBd classes would be required, for both male and female, in individual and doubles categories. Another area of study would be regarding the main types of shots which lead to unforced errors. Related studies on the distance that a player moves on the court would also provide greater insights into the demands of PBd.

Conclusion

This study concludes that there are significant differences between the WH1 and WH2 classes. These sports classifications that allocate similar disabilities in predetermined classes are a fundamental requirement for providing a level playing field for players. The classes' main differences are the higher intensity in WH2 class matches and technical aspects with greater frequency of technical actions performed by WH2 players, including shots that require more speed, like the Drive or Smash. The information generated in this research can assist coaches during training to guide the development of the temporal and technical aspects of the PBd, as well as monitor them during matches to obtain victory.

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References

Abian-Vicent, J., Castanedo, A., Abian, P., & Sampedro, J. (2013). Temporal and Notational Comparison of Badminton Matches Between Men's Singles and Women's Singles. *International Journal of Performance Analysis in Sport*, 13(2), 310-320.

Antunes, D., Rossato, M., Kons, R. L., Sakugawa, R. L., & Fischer, G. (2017). Neuromuscular features in sprinters with cerebral palsy: case studies based on paralympic classification. *Journal of Exercise Rehabilitation*, 13(6), 716-721.

Barreira, J., Chiminazzo, J. G. C., & Fernandes, P. T. (2016). Analysis of point difference established by winners and losers in games of badminton. *International Journal of Performance Analysis in Sport*, 16, 687-694.

Beckman, E. M., Connick, M. J., & Tweedy, S. M. (2017). Assessing muscle strength for the purpose of classification in Paralympic sport: A review and recommendations. *Journal of Science and Medicine in Sport*, 20(4), 391-396.

Burkett, B., Payton, C., Van de Vliet, P., Jarvis, H., Daly, D., Mehrkuehler, C., . . . Hogarth, L. (2018). Performance Characteristics of Para Swimmers: How Effective Is the Swimming Classification System? *Physical Medicine and Rehabilitation Clinics of North America*, 29(2), 333-346.

BWF, B. W. F. (2020). Para badminton. Retrieved from https://corporate.bwfbadminton.com/para-badminton/

Cabello-Manrique, D., & Gonzalez-Badillo, J. (2003). Analysis of the Characteristics of Competitive Badminton. *British Journal of Sports Medicine*, 37, 62-66.

Chiminazzo, J. G. C., Barreira, J., Luz, L. S. M., Saraiva, W. C., & Cayres, J. T. (2018). Technical and timing characteristics of badminton men?s single: comparison between groups and play-offs stages in 2016 Rio Olympic Games. *International Journal of Performance Analysis in Sport*, 18, 1-10.

Chiminazzo, J. G. C., Ferreira, R., Castanho, G. K. F., Barreira, J., & Fernandes, P. T. (2017). Fewer mistakes for more winning: a badminton analysis. *Brazilian Journal of Science and Movement*, 25(2), 115-121.

Fernandez-Fernandez, J., Sanz-Rivas, D., & Mendez-Villanueva, A. (2009). A Review of the Activity Profile and Physiological Demands of Tennis Match Play. *Strength and Conditioning Journal*, 31(4), 15-26.

Haydon, D. S., Pinder, R. A., Grimshaw, P. N., & Robertson, W. S. P. (2018). Overground-Propulsion Kinematics and Acceleration in Elite Wheelchair Rugby. *International Journal of Sports Physiology and Performance*, 13(2), 156-162.

IPC, I. P. C. (2014). PC Governing Board approves first 16 sports to be included in the Tokyo 2020 Paralympic Games. Retrieved from https://www.paralympic.org/news/ipc-governing-board-approves-first-16-sports-be-included-tokyo-2020-paralympic-games

Landis, J. R., & Koch, G. G. (1977). The Measurement of Observer Agreement for Categorical Data. *Biometrics*, 33(1), 159-174.

Latino, F., Cassese, F. P., & Tafuri, D. (2018). Badminton: from competitive motor activity to inclusive didactics *Acta Medica Mediterranea*, 34, 1521-1524.

Phomsoupha, M., & Laffaye, G. (2015). The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics. *Spors Medicine*, 45(4), 473-495.

Rhodes, J. M., Mason, B. S., Malone, L. A., & Goosey-Tolfrey, V. L. (2015). Effect of team rank and player classification on activity profiles of elite wheelchair rugby players. *Journal of Sports Science*, 33(19), 2070-2078.

Ribeiro, W. M., & Almeida, M. B. (2020). Performance analysis in wheelchair para-badminton matches. *International Journal of Racket Sports Science*, 2(1), 22-31.

Rietveld, T., Vegter, R. J. K., van der Slikke, R. M. A., Hoekstra, A. E., van der Woude, L. H. V., & de Groot, S. (2019). Wheelchair mobility performance of elite wheelchair tennis players during four field tests: Inter-trial reliability and construct validity. *PLoS One*, 14(6), e0217514.

Strapasson, A. M., Baessa, D. J., Borin, J. P., & Duarte, E. (2017). Para-Badminton: principles of the game measurement through the scout. *Brazilian Journal of Science and Movement*, 25(2), 107-115.

Strapasson, A. M., Chiminazzo, J. G. C., Ribeiro, W. O. M., Almeida, M. B., & Duarte, E. (2018). Para-badminton: technical and temporal characteristics. *Caderno de Educação Física e Esporte*, 16(2), 1-7.

Tweedy, S. M., Mann, D., & Vanlandewijck, Y. C. (2016). Research needs for the development of evidence-based systems of classification for physical, vision, and intellectual impairments. In Y. C. Vanlandewijck & W. R. Thompson (Eds.), *Training and Coaching the Paralympic Athlete* (pp. 122-149). Hoboken, NJ: John Wiley & Sons, Ltd.

Tweedy, S. M., & Vanlandewijck, Y. C. (2011). International Paralympic Committee position stand-background and scientific rationale for classification in paralympic sport. *British Journal of Sports Medicine*, 10, 1136-1186.

Ungerer, G. (2018). Classification in para sport for athletes following cervical spine trauma. In B. Hainline & R. A. Stern (Eds.), *Handbook of Clinical Neurology* (Vol. Sports Neurology, pp. 371-377): Elsevier.

Zemková, E., Muyor, J. M., & Jeleň, M. (2018). Association of Trunk Rotational Velocity with Spine Mobility and Curvatures in Para Table Tennis Players. *International Journal of Sports Medicine*, 39(14), 1055-1062.

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Knowledge and Competences of Racket Sports Coaches: What do They Think and Know?

Conocimientos y competencias de los entrenadores de deportes de raqueta: ¿qué piensan y qué saben?

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Abstract

This study analyzed the professional, interpersonal, and intrapersonal knowledge as well as the most important competences to Brazilian coaches who work with four different racket sports (badminton, squash, tennis, and table tennis). A total of 150 coaches (122 men and 28 women) participated in this study, most of whom were tennis coaches (n=68), followed by badminton (n=39), table tennis (n=21), squash (n=17), and more than one racket sport (n=5). For data collection, a socio-demographic questionnaire and the Coaches' Knowledge and Competence Questionnaire (CKCQ) (Quinaud et. al., 2018) were applied. The Wilcoxon test was used to compare the importance and domain attributed by the coaches to the items. In general, knowledge and competences had high scores of attributed importance and perceived domain. However, knowledge of program implementation and evaluation, professional development of coaches and competence to develop the coaching philosophy had the lowest values of perceived domain.

Keywords: *coaches, knowledge, competences, racket sports.*

Resumen

Este estudio analizó los conocimientos profesionales, interpersonales e intrapersonales, así como las competencias consideradas más importantes para los entrenadores brasileños que trabajan con cuatro deportes de raqueta diferentes (bádminton, *squash*, tenis y tenis de mesa). Un total de 150 entrenadores (122 hombres y 28 mujeres) participaron en este estudio, la mayoría de ellos eran entrenadores de tenis (47 %), seguidos de bádminton (28 %), tenis de mesa (16 %) y *squash* (12 %). Los datos se recolectaron mediante un cuestionario sociodemográfico y el cuestionario de conocimientos y competencias de los entrenadores (CKCQ, por su sigla en inglés) (Quinaud et. al, 2018). Se utilizó la prueba de Wilcoxon para comparar la importancia y el ámbito atribuidos por los entrenadores a los ítems. En general, los conocimientos y las competencias tuvieron altas puntuaciones de importancia atribuida y ámbito percibido; sin embargo, los conocimientos de implementación y evaluación de programas, desarrollo profesional de los entrenadores y la competencia para desarrollar la filosofía del entrenamiento tuvieron los valores más bajos de ámbito percibido.

Palabras clave: *entrenadores, conocimientos, competencias, deportes de raqueta.*

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Introduction

The four main types of racket sports, namely badminton, squash, table tennis, and tennis, have gained popularity in different countries worldwide and have received increasing attention from the scientific literature (Lees, 2003; O'Donoghue, Girard & Reid, 2013). Researchers from different areas seek to identify factors that make it possible to promote the improvement of sports performance, with most of the research being developed in the fields of physiology, nutrition, biomechanics, and medicine (Lees, 2003). Coaches, who play a central role in athletes' development, have been little explored in racket sports literature. Their knowledge and competences are decisive for professional success and should be constantly addressed by research to indirectly improve athletes' development process.

The scientific literature on sports coaches reveals the diverse roles and responsibilities played by professionals in this position, such as developing youth positive development, athletic performance and promoting health (Côté & Gilbert, 2009; International Council for Coaching Excellence [ICCE], 2013; Galatti, Cortela, Silva, Misuta & Belli, 2017). In their various roles, coaches need to develop the necessary knowledge for their practice, which according to the ICCE (2013) can be summarized into (i) professional knowledge, which is the specific knowledge of the sport, in addition to knowledge within the sports sciences (Abraham, Collins, & Martindale, 2006); (ii) interpersonal knowledge, which is the knowledge obtained through bonding with athletes, coaching staff, parents, and other professionals; and (iii) intrapersonal knowledge, which is the understanding of oneself along with the process of reflection and introspection (Côté & Gilbert 2009).

Coaches must also develop basic competences to be more effective (ICCE, 2013). The competences suggested by the ICCE were based on the three types of knowledge of sports coaches and are described as: defining the vision and strategy; shaping the environment; building relationships; conducting training sessions and preparing and managing competitions; reading and reacting to the "field"; learning to reflect.

In a review on coaching studies, Gilbert and Trudel (2004) identified a focus on coaching behavior research, and a primary emphasis on team sports in school contexts. More recently, Griffo et al. (2019) verified that approximately one-third of international publications on coaching refer to coaching methods related to developing competences and knowledge. A similar scenario was found in the Brazilian literature, revealing an increase in publications about coaches from 2000 to 2015 related to thinking (perception, belief, emotions, philosophy, knowledge), which is the most researched topic (Galatti et al., 2016). From these reviews, few refer to racket sports.

In the international context, a recent review identified only 10 papers focused on racket sports coaches, published in English in Europe, North America and Brazil (Cardoso, Motta, Belli, Cortela & Galatti, 2019). In the Brazilian context, we only found studies on tennis, led by the same group of authors (Corrêa Cortela et al., 2019; Corrêa Cortela, Balbinotti, Tozetto, Both, & Milistetd, 2017; Corrêa Cortela, Milistetd, Galatti, Crespo, & Balbinotti, 2016, 2017). Therefore, Brazil has become one of the pioneer countries in developing research on the knowledge and competences of racket sports coaches, but mainly focused on tennis (Corrêa Cortela et al., 2019; Corrêa Cortela, Balbinotti, Tozetto, Both, & Milistetd, 2017; Corrêa Cortela, Milistetd, Galatti, Crespo, & Balbinotti, 2016, 2017).

In addition to its literature, Brazil has emerged as a power within international competitions, with international top-100 athletes in several sports and expressive results in the continent, as in the Pan-American and Parapan-American games of Lima, 2019. In the Pan-American, Brazilian racket sports athletes won four gold, six silver, and four bronze medals. In the Parapan American Games, the results were even more expressive, with 13 gold, 10 silver, and 12 bronze medals (https://wrsd.lima2019.pe/).

This study aimed to identify the most important types of knowledge and competences declared by racket sports coaches for coaching in the Brazilian context. When investigating and understanding the coaches' perceptions about what matters for their professional practice, we seek to contribute with valuable information for the improvement of coaching education programs in racket sports. The study hypothesizes that racket coaches attribute higher importance to knowledge and competencies that they master, along with a higher domain of professional knowledge compared to interpersonal and intrapersonal knowledge.

Materials and methods

This quantitative research has a descriptive character (Thomas, Nelson, & Silverman, 2012) using the survey method by a questionnaire, aiming to investigate the knowledge and competences of racket sports coaches.

A total of 150 coaches from four racket sports participated in the study from 19 states of Brazil. The mean age was 37.15 years (standard deviation = 10.52 years). Table 1 presents the information of the participants concerning the sport which they act as a coach, if they have already experienced a racket sport or not, and the last academic education. The inclusion criteria for the participants in this study were: adults aged over 18 years and acting as a coach of one of the following four racket modalities: badminton, squash, tennis, or table tennis. Participants included only coaches who showed interest and voluntarily accepted to participate. This research was approved by the University Research Ethics Committee (CAAE number: 02627418.0.0000.5404).

Table 1.
Participants' information.

	Men	Women	Total
	122	**28**	**150**
Sport			
Badminton	30	9	39
Squash	15	2	17
Tennis	56	12	68
Table Tennis	17	4	21
More than one racket sport	4	1	5
Sports Experience			
Racket sports	116	26	142
Did not experience racket sports	6	2	8
Latest academic education			
Complete High School	3	0	3
Incomplete High School	1	0	1
Complete Higher Education	13	3	16
Higher Education in Physical Education	41	14	55
Incomplete Higher Education	14	0	14
Master's degree/ PhD degree/ MBA	18	2	20
Specialization	31	9	40
Others	1	0	1

Design and procedures

Instruments

A questionnaire made up of two parts was applied:

- A socio-demographic questionnaire, created and refined via evaluation of researchers from a sports pedagogy laboratory located in the state of São Paulo, presenting questions (n = 21) that provided a detailed profile of racket sports coaches. The socio-demographic questionnaire covered topics such as age, sex, context of activity, target audience, competitive level, time of activity, weekly working hours as a coach, time of completion of the latest course taken related to coaching and source income. The questionnaire consisted of open and closed questions.
- The "Coaches' Knowledge and Competence Questionnaire" (CKCQ,Quinaud et al., 2018). CKCQ is a validated instrument that allows researchers to understand the different dimensions of knowledge and competences (Côté & Gilbert, 2009; ICCE, 2013) of sports coaches (Quinaud et al., 2018). CKCQ contains 38 questions divided into "knowledge" (20 questions) and "Competences" (18 questions). "Knowledge" addresses professional (n = 10), interpersonal (n = 5) and intrapersonal (n = 5) knowledge, while "Competences" contains questions about defining vision and strategy (n = 3), shaping the environment (n = 3), building relationships (n = 3), performing practices (n = 3), reading and reacting to the "field" (n = 3), and learning and reflecting (n = 3). The participants answered the questions of CKCQ through a Likert scale referring to the importance (from 1 = "not important" to 5 = "very important") and the perceived domain (from 1 = "I do not know" to 5 = "I know a lot") attributed to a given subject.

Attributed importance refers to the level of importance the participant attributes to a given theme (in our study certain knowledge or competence) regarding the performance of the coach of racket sports. Perceived domain in turn is the perception of how much knowledge or competence the participant has as a coach.

Procedures

The existing groups on Facebook® that address the four racket modalities were identified based on their posts and objectives. Sixteen groups that could reach the coaches of the chosen modalities were selected. Within each group, a brief description of the research objectives and the questionnaire URL was posted, in addition to the main researcher's contact information, in snowball sampling (Baltar & Brunet, 2012). The period for accepting responses ranged from 02/19/2019 to 04/29/2019, totaling 70 days.

Upon entering the questionnaire link, the participant had access and was asked to confirm awareness of the Free and Informed Consent Term. For this study, in addition to the socio-demographic questionnaire, the CKCQ knowledge questionnaire was mandatory for all participants, leaving the CKCQ competences questionnaire as non-mandatory. Out of the total participants, 137 accepted and answered the CKCQ competences questionnaire (91.3%).

Data analysis

Descriptive statistics were used to summarize and present data. For such, we used measures of position (mean) and dispersion (standard deviation). The normality of the data was assessed with histograms and by the statistical test of Shapiro Wilk. The Wilcoxon test was used to compare the values attributed by the participants to the importance and domain in each knowledge and competence evaluated. The test was chosen for being a non-parametric statistical analysis for paired data. Cohen's d Effect Size (ES) was adopted to analyze the magnitude of the effect. For the interpretation of magnitude, ES < 0.20 was considered a small effect, from 0.20 to 0.50 was considered a medium effect and above 0.50 was considered a large effect (Cohen, 1977). To compare the scores in importance and domain for knowledge and competence we used Friedman test paired with Dunn's post-hoc test. The level of significance was set at 0.05. All analyses were performed using the statistical software MATLAB (The MathWorks Inc., Natick, MA, USA).

Results

Table 2 presents the scores regarding the attributed importance and perceived domain about professional, interpersonal, and intrapersonal knowledge.

The results presented in Table 2 show that although racket sports coaches attributed high values of importance and domain to professional, interpersonal and intrapersonal knowledge, the coaches attributed more importance than ability to the items investigated.

Table 2.
Attributed importance and perceived domain about the knowledge of racket sports coaches.

		Importance		Domain		ES	p-value
	Knowledge	**Mean**	**SD**	**Mean**	**SD**		
Professional	1.1 – Training planning (objectives, task structure and context progressions)	4.7	0.5	4.2	0.7	0.82	<0.01
	1.2 – Training management (time, physical space, equipment)	4.5	0.7	4.2	0.7	0.42	<0.01
	1.3 – Pedagogical intervention (instruction in training, correction, orientation, organization of tasks and progressions)	4.5	0.7	4.2	0.7	0.42	<0.01
	1.4 – Assessment of technical-tactical, physical and psychological aspects in the context of sports training	4.6	0.7	4.0	0.8	0.79	<0.01
	1.5 – Training and long-term development of athletes (initiation, specialization and improvement)	4.4	0.8	3.8	0.9	0.70	<0.01
	1.6 – Implementation and evaluation of training programs	4.1	1.0	3.2	1.1	0.85	<0.01
	1.7 – First-aid measures	3.9	1.0	3.4	1.0	0.5	<0.01
	1.8 – Legislation regulating the sports system (rules and regulations of specific confederations)	3.7	1.1	3.2	1.0	0.47	<0.01
	1.9 – Context of professional performance (recreation, development, performance)	4.0	0.9	3.9	0.8	0.11	0.03
	1.10 – Organization of sports competitions	4.3	0.8	4.2	0.9	0.11	0.30
Interpersonal	1.11 – Leadership and management of athletes and coaching staff	4.3	0.8	3.9	1.0	0.44	<0.01
	1.12 – Effective communication during training	4.7	0.6	4.4	0.7	0.46	<0.01
	1.13 – Professional development of coaches	4.3	0.9	3.5	1.1	0.79	<0.01
	1.14 – Communication with other actors in the sports context (parents, media, referees)	4.3	0.8	3.9	0.9	0.47	<0.01
	1.15 – Development of attitudes, values and behaviors of athletes	4.7	0.6	4.3	0.8	0.56	<0.01
Intrapersonal	1.16 – Personal strategies for self-learning	4.5	0.7	4.1	0.8	0.53	<0.01
	1.17 – Reflection about their own practice	4.4	0.7	4.1	0.8	0.39	<0.01
	1.18 – Their own emotion and emotion of others (athletes, parents, media, referees)	4.3	0.8	4.0	0.9	0.35	<0.01
	1.19 – The very training philosophy (principles, values, beliefs)	4.3	0.8	4.0	0.9	0.35	<0.01
	1.20 – Awareness and criticism of professional practice	4.3	0.8	4.1	0.9	0.23	<0.01

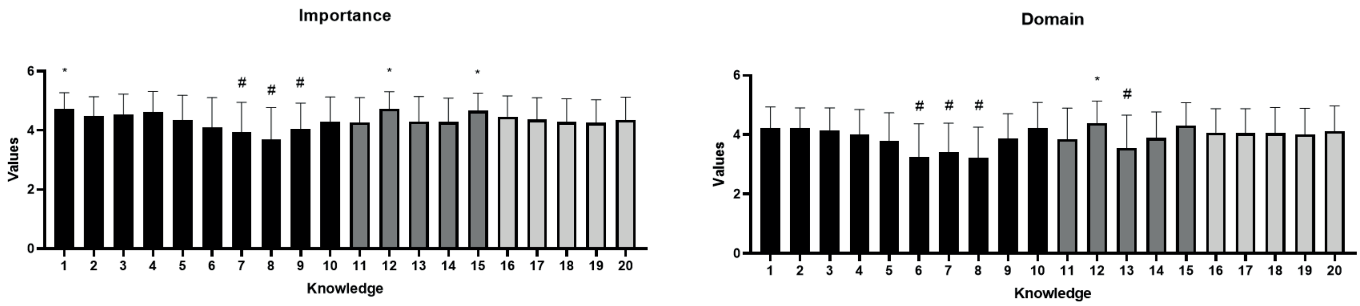

Figure 1. Comparison between the attributed importance and perceived domain about the knowledge of racket sports coaches. Legend: * significantly higher; # significant lower in Friedman test (p<0.001).

Figure 1 presents the comparison between the types of knowledge. The highest mean values on the importance attributed to knowledge were found for: training planning (1), effective communication during training (12) and development of attitudes, values and behaviors of athletes (15). The lowest values were: first aid (7), legislation regulating the sports system (8), and context of professional performance (9). Regarding perceived domain, the highest mean values were: effective communication during training (12). The lowest values presented regarding perceived domain were: implementation and evaluation of programs (6), first aid (7), legislation regulating the sports system (8), and professional development of coaches (13).

The mean score in each knowledge area is shown in Table 3.

Table 3.
Mean (and standard deviation) attributed importance and perceived domain about the dimensions of knowledge of racket sports coaches.

	Importance	Domain	p-value	ES
Professional	4.2 (0.5)	3.8 (0.6)	<0.001	0.72
Interpersonal	4.4 (0.5)	3.9 (0.7)	<0.001	0.82
Intrapersonal	4.3 (0.6)	4.0 (0.7)	<0.001	0.46

ES = effect size.

All kinds of knowledge had higher attributed importance value than perceived domain. As much as professional knowledge displays more themes than other kinds of knowledge, this specific type together with interpersonal knowledge showed larger difference between the attributed importance and perceived domain than intrapersonal knowledge, based on effect size (ES).

The results of the mean scores about the importance attributed and perceived domain of competencies presented in CKCQ are presented in Figures 2 and 3.

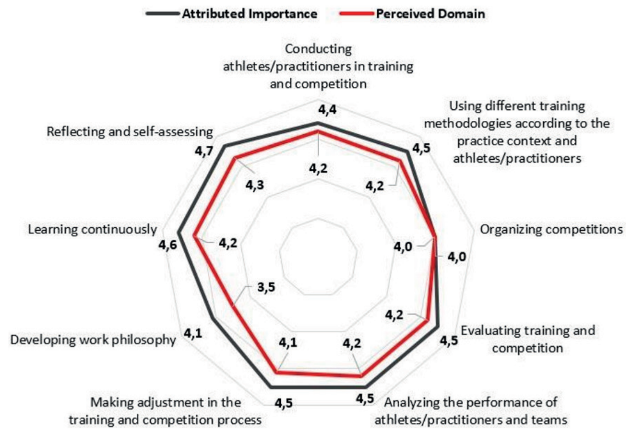

Figure 2. Attributed importance and perceived domain about the competences of racket sports coaches (part 1).

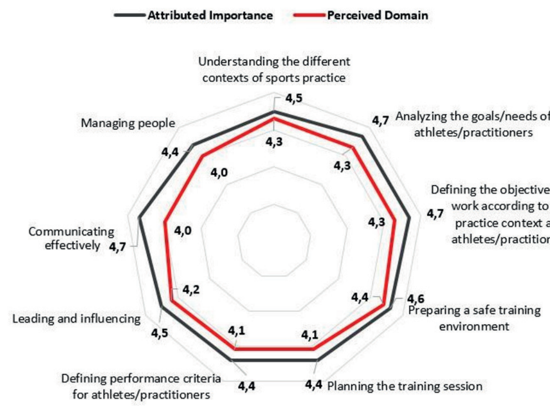

Figure 3. Attributed importance and perceived domain about the competences of racket sports coaches (part 2).

For the results of coaching competences (Figures 2, 3 and 4), there was also a significant difference between the values of attributed importance and perceived domain in almost all the analyzed items. The task of organizing competitions, a competency within the category of directing training sessions and preparing and managing competitions, was the only one that did not present significant difference, thus demonstrating that for coaches this competence receives the same degree of importance and domain.

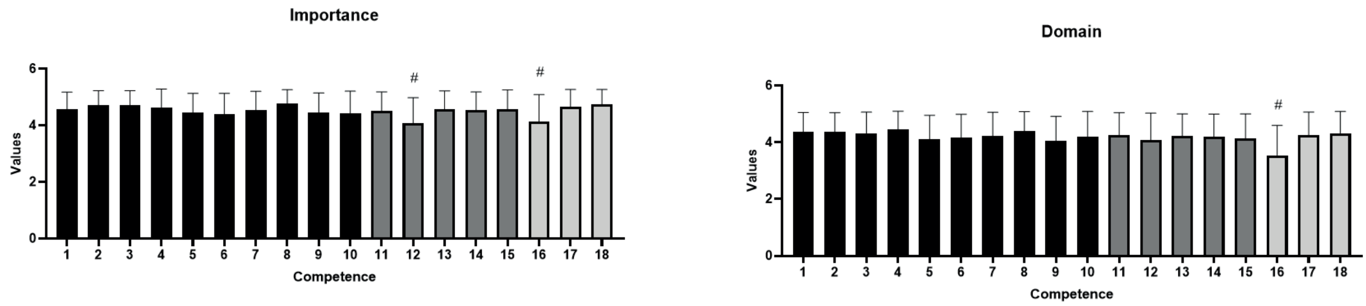

Figure 4. Comparison between the attributed importance and perceived domain about the competence of racket sports coaches. Legend: # significantly lower in Friedman test (p<0.001).

Both for importance and domain, item (16), developing a philosophy of coaching, appears as the lowest value. In terms of importance, item (12) regarding organizing competitions also appears as the lowest value.

Lastly, Figure 5 presents the mean scores for attributed importance and perceived domain of the dimensions of the competencies presented.

Regarding the dimensions of competencies, our results also showed high mean values in attributed importance and in perceived domain, even though the latter presents lower mean values compared to the values of importance attributed by racket sports coaches.

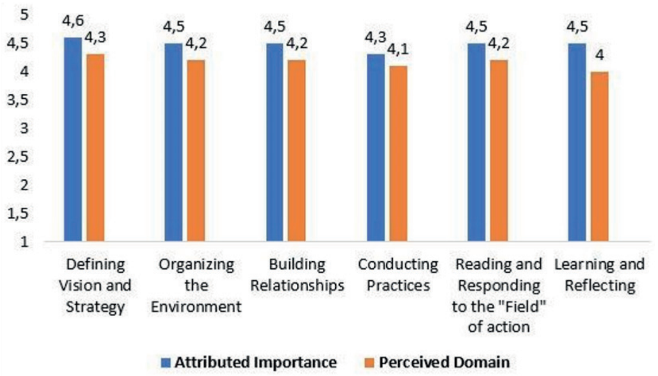

Figure 5. Attributed importance and perceived domain about the competences of racket sports coaches (part 2).

Discussion

This study analyzed the importance of the types of knowledge (professional, interpersonal and intrapersonal) and their respective competences, as well as the perceived domain of racket sports coaches. The results showed that, even though knowledge dimension presented higher values of attributed importance compared to perceived domain, professional and interpersonal knowledge showed a large difference when analyzing effect size (ES), differing from intrapersonal knowledge, which showed a medium effect size (ES). The hypotheses presented in the introduction were confirmed by the results obtained, which suggests that racket sports coaches perceive importance and domain of this knowledge within their professional performance.

Looking at these questions individually, we found that coaches attribute high mean values for the importance of knowledge and competences, which differs from the values of perceived domain of knowledge and competences that are essential to sports coaches. Some studies analyzing professional knowledge and competences also showed high values of self-perception of importance and domain (Corrêa Cortela, Balbinotti, et al., 2017; Corrêa Cortela, Milistetd, et al., 2016, 2017; Egerland, Nascimento, & Both, 2010; Egerland, Salles, Barroso, Baldi, & Nascimento, 2013).

The coaches as whole attributed high values of self-perception of professional knowledge, but when comparing coaches of collective sports and of individual sports, the latter group showed a lower perception mainly for the professional knowledge of the biomechanics of the sport and the professionals of communication and integration of the sport (Egerland, Nascimento, & Both, 2010). For university coaches, self-perceived competence values were also high, with a significant difference in competence related to sports management and legislation between coaches of team sports and individual sports, also showing that coaches of team sports perceive themselves as better at this competence (Egerland, Salles & Baldi, 2014). Despite using different instruments, the studies cited are in line with our main results, thus advancing legislation and sports management as a possible weakness of individual sports coaches and racket sports coaches. As for tennis coaches, the importance attributed to professional knowledge compared to self-inspection of their domain (Corrêa Cortela, Milistetd et al., 2017) showed high values, which was also reported in the present study with racket sports coaches.

The legislation that regulates the sports system showed one of the lowest mean values for both importance (3.7) and domain (3.2), which is also found for tennis and other types of coaches (Corrêa Cortela et al., 2019; Corrêa Cortela, et al., 2016; Egerland et al., 2010). In a study by Egerland et al. (2013), the ability to provide some first-aid care was not shown to be important and was little acknowledged by coaches, corroborating the results found in this study for both perceptions (3.9 for importance and 3.4 for domain).

The data regarding the implementation and evaluation of programs also proved to be a topic of low domain on the part of coaches (3.2), contrasting with studies in which values of high or equal domain are reported (Corrêa Cortela, Balbinotti, et al., 2017; Egerland et al., 2010, 2013). One of the alternatives for coaches' development in this domain is offering a management topic in coaching education programs, since within the sports management field there is a sub-area called "legal aspects of sport" (Rocha & Bastos, 2011). Having a sports manager dealing with policies, developing planning and marketing actions would be expected (Mazzei & Júnior, 2017; Amaral & Bastos, 2015). On the other hand, offering basic knowledge on the subject in courses for coaches is relevant, especially in youth sport or less structured clubs, where it is usual for racket sports coaches to get involved in competitions of complex marketing and management structure, in addition to assisting the management of athlete contracts.

The coaches' professional development stood out within the interpersonal knowledge for having the lowest mean value of perceived domain. As most studies on the knowledge and competences of tennis coaches are focused on the professional area (Corrêa Cortela, Balbinotti, et al., 2017; Corrêa Cortela, Milistetd, et al., 2016, 2017), gaps concerning the interpersonal and intrapersonal knowledge of racket sports coaches become evident, since in order to achieve excellence as a coach these three kinds of knowledge are required (Côté & Gilbert, 2009). One possibility for improving the domain of coaches regarding the professional development of coaches would be a bigger investment on actions to incite relations between coaches in non-formal contexts (such as workshops and minicourses) (Galatti, Santos & Korsakas, 2019) and informal contexts (such as coaching place, talking to other coaches or even having one coach as a mentor for another) for their learning, especially since those are learning contexts that are broadly used by coaches (Corrêa Cortela, Milistetd, Both, Fuentes, Balbinotti, 2020; Walker, Thomas & Driska, 2018).

Among all competences, the lowest perceived domain value (3.5) was the competence related to developing a coaching philosophy. Although the concept of the coaching philosophy is still not well solidified (Cushion & Partington, 2016), the coach's philosophy, values and beliefs act as a basis for their intrapersonal knowledge in reflection and self-learning process, thus exerting a major role on the competences developed by trainers (Galatti et al., 2019; Milistetd, Galatti, Collet, Tozetto, & Nascimento, 2017).

Even though there are few studies that mention the development of coaching philosophy for racket sports coaches, some possibilities are offered to start the development of such philosophy. The first one is a mentoring action between coaches that can provide opportunities for exchanging experiences and acquiring knowledge (González-Rivera, Campos-Izquierdo, Villalba & Hall, 2017; Stoszkowski & Collins, 2016; Winfield, Williams & Dixon, 2013). Lastly, reflecting on their practice can help reinforce and expand knowledge, which can occur in several ways; here we highlight the use of reflective cards (Rodrigue & Trudel, 2018; Winfield, Williams & Dixon, 2013; Hughes, Lee & Chesterfield, 2009), a simple tool that allows coaches "to learn how to develop and improve their personal competences" (Hughes, Lee & Chesterfield, 2009, p. 371), among them competences related to coaching philosophy.

Conclusion

Based on the results of this study, most types of knowledge and competences are of high perceived importance and domain by the coaches of the four racket sports. However, for certain professional types of knowledge such as the implementation and evaluation of programs, first aid and legislation regulating the sports system, we note low domain presented by the coaches, demonstrating areas that can be addressed and explored within the training courses of coaches through federations or confederations. Despite this, the domain indicated by the coaches regarding professional development of coaches is also inferior compared to other topics within interpersonal knowledge; thus, the provision of activities in pairs within coaching courses can be an alternative in order to create a network between participants and enable development among coaches.

We reinforce the need for future studies that analyze the phenomenon from different perspectives, such as interviews with coaches or field work that allows to evaluate knowledge and competences they use within their routine as coaches. However, we believe that, from the same point, it is possible to create or reformulate training courses based on the exposed data, since actions based on the coaches' needs act more effectively than those that do not meet the essential demands of course participants, that is, coaches.

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References

Abraham, A., Collins, D., & Martindale, R. (2006). The coaching schematic: Validation through expert coach consensus. *Journal of Sports Sciences*, 26(06), 549–564. https://doi.org/10.1080/02640410500189173

Amaral, C. M. S., & Bastos, F. C. (2015). O gestor esportivo no Brasil: revisão de publicações no país. *Revista Intercontinental de Gestão Desportiva*, 5(1), 68-78.

Baltar, F., & Brunet, I. (2012). Social research 2.0: virtual snowball sampling method using Facebook. *Internet Research*, 22(1), 57–74. https://doi.org/10.1108/10662241211199960

Cardoso, C., Motta, M.D.C., Belli, T., Cortela, C.C., & Galatti, L.R. (2019, December). Produções em Revistas Científicas sobre Treinador(a)/Professor(a) nos Esportes de Raquete: análise quantitativa. *Anais do Congresso Brasileiro de Educação Física do Centro-Oeste*, Cuiabá, MT, Brasil, 6. Recuperado de http://periodicoscientificos.ufmt.br/ojs/index.php/corpoconsciencia/issue/view/561/showToc

Cohen, J. (1977). *Statistical Power Analysis for the Behavioral Sciences*. New York, NY: Academic Press.

Corrêa Cortela, C., Balbinotti, C. A. A., Tozetto, V. B., Both, J., & Milistetd, M. (2017). Associação entre formação inicial e autopercepção de competência profissional de treinadores de tênis. *Journal of Sport Pedagogy and Research2*, 2(3), 32–42.

Corrêa Cortela, C., Gonçalves, G. H. T., Klering, R. T., & Balbinotti, C. A. A. (2016). O "Estado da Arte" das publicações sobre tênis em periódicos nacionais. *Coleção Pesquisa Em Educação Física*, 15(2), 143–151.

Corrêa Cortela, C., Milistetd, M., Galatti, L. R., Crespo, M., & Balbinotti, C. A. A. (2016). Professional knowledge of tennis coaches. *ITF Coaching and Sport Science Review*, 70(24), 10–12.

Corrêa Cortela, C., Milistetd, M., Galatti, L. R., Crespo, M., & Balbinotti, C. A. A. (2017). Professional competencies in tennis coaching. *ITF Coaching and Sport Science Review2*, 71(25), 3–5.

Corrêa Cortela, C., Milistetd, M., Both, J., Galatti, L.R., Crespo, M., & Balbinotti, C.A.A. (2019). Formação continuada e autopercepção de competencia: um estudo com treinadores de tênis. *Revista de Ciencias del Ejercicio y la Salud*, 17(2), 1-15. https://doi.org/10.15517/pensarmov.v17i2.36948

Corrêa Cortela, C., Milistetd, M., Both, J., Fuentes, J.P., & Balbinotti, C.A.A. (2020). Desenvolvimento profissional de treinadores de tênis: situações e contextos de aprendizagem. *Retos*, 38, 700-707.

Côté, J., & Gilbert, W. (2009). An integrative definition of coaching effectiveness and expertise. *International Journal of Sports Science & Coaching*, 4(3), 307–323.

Cushion, C., & Partington, M. (2016). A critical analysis of the conceptualisation of 'coaching philosophy.' *Sport, Education and Society*, 21(6), 851–867. https://doi.org/10.1080/13573322.2014.958817

Egerland, E. M., Nascimento, J. V. do, & Both, J. (2010). Competência profissional percebida de treinadores esportivos catarinenses. *Revista de Educação Física/UEM*, 21(3), 457–467. https://doi.org/10.4025/reveducfis.v21i3.8285

Egerland, E. M., Salles, W. das N., Barroso, M., Baldi, M., & Nascimento, J. V. do. (2013). Potencialidades e necessidades profissionais na formação de treinadores desportivos. *Revista Brasileira de Ciência e Movimento*, 21(1), 31–38. https://doi.org/10.18511/0103-1716/rbcm.v21n2p31-38

Egerland, E.M., Salles, W.das N., Baldi, M.F. (2014). Perception of professional competence of Brazilian college coaches. *Revista Brasileira de Cineantropometria e Desempenho Humano*, 16(4), 437-446. https://doi.org/10.5007/1980-0037.2014v16n4p437

Galatti, L. R., Bettega, O. B., Brasil, V. Z., Sobrinho, A. E. P. de S., Bertram, R., Tozetto, V. B., ... Milistetd, M. (2016). Coaching in Brazil - Sport coaching as a profession in Brazil: an analysis of the coaching literature in Brazil from 2000 - 2015. *International Sport Coaching Journal*, 3, 316–331. https://doi.org/10.1123/iscj.2015-0071

Galatti, L.R., Cortela, C.C., Silva, W.G.F., Misuta, M.S., & Belli, T. (2017). Theoretical and practical knowledge for table tennis coaches development in a Sports Science Bachelor's Degree. In M. Kondrič, M. Fuchs & T. Matjašič (Ed.), *Proceedings Book of the 15th ITTF Sports Science Congress, Dusseldorf, May 27th – 28th, 2017* (pp. 381-387). Switzerland: International Table Tennis Federation.

Galatti, L.R., Milistetd, M., Quinaud, R., Mazzei, L.C., Seoane, A.M., & Paes, R.R. (2019). Scaffolding a Club Philosophy Among Coaches: Perspectives from a Spanish Club. *Journal of Sport Psychology*, 28, 24-34.

Galatti, L.R., Santos, Y.Y.S. & Korsakas, P. (2019). A Coach Developers' Narrative on Scaffolding a Learner-Centred Coaching Course in Brazil. *International Sport Coaching Journal*, 6, 339-348. https://doi.org/10.1123/iscj.2018-0084

Gilbert, W. D., & Trudel, P. (2004). Analysis of Coaching Science *Research Published from 1970-2001. Research Quarterly for Exercise and Sport*, 75(4), 388-399. https://doi.org/10.1080/02701367.2004.10609172

González-Rivera, M.D., Campos-Izquierdo, A., Villalba, A.I., & Hall, N.D. (2017). Sources of knowledge used by Spanish coaches: a study according to competition level, gender and profesional experience. *International Journal of Sports Science & Coaching*, 12(2), 162-174. https://doi.org/10.1177/1747954117694733

Griffo, J.M., Jensen, M., Anthony, C.C., Baghurst, T., & Kulinna, P.H. (2019). A decade of research literature in sport coaching (2005-2015). *International Journal of Sports Science & Coaching*, 14(2), 1-11. https://doi.org/10.1177/1747954118825058

Hughes, C., Lee, S., & Chesterfield, G. (2009). Innovation in sports coaching: the implementation of reflective cards. *Reflective Practice*, 10(3), 367-384. https://doi.org/10.1080/14623940903034895

International Council for Coaching Excellence (ICCE). (2013). International Sport Coaching Framework Version 1.2. *Champaign: Human Kinetics*.

Lees, A. (2003). Science and the major racket sports: a review. *Journal of Sports Sciences*, 21, 707–732. https://doi.org/10.1080/0264041031000140275

Mazzei, L.C., & Júnior, A.J.R. (2017). Um ensaio sobre a Gestão do Esporte: Um momento para a sua afirmação no Brasil. *Revista de Gestão e Negócios do Esporte (RGNE)*, 2(1), 96-109.

Milistetd, M., Galatti, L.R., Collet, C., Tozetto, V.B., & Nascimento, J.V. do. (2017). Formação de treinadores esportivos: orientações para a organização das práticas pedagógicas nos cursos de bacharelado em educação física. *Journal of Physical Education and Sport*, 28, 1–14. https://doi.org/10.4025/jphyseduc.v28i1.2849

O'Donoghue, P., Girard, O., & Reid, M. (2013). Racket Sports. In *Routledge Handbook of Sports Performance Analysis*. https://doi.org/10.4324/9780203806913

Quinaud, R.T., Backes, A.F., Da Silva, D.C., Nascimento, J.V. do, Ramos, V., & Milistetd, M. (2018). Construction and content validity of the coaches' knowledge and competence questionnaire - CKCQ. *Revista Brasileira de Cineantropometria e Desempenho Humano*, 20(3), 318–331. https://doi.org/10.5007/1980-0037.2018v20n3p318

Rocha, C.M., & Bastos, F.C. (2011). Gestão do Esporte: definindo a área. *Revista Brasileira de Educação Física e Esporte*, 25, 91-103. https://doi.org/10.1590/s1807-55092011000500010

Rodrigue, F., & Trudel, P. (2018). Reflective Practice: a case study of a university football coach using reflective cards. *LASE Journal of Sport Science*, 9(1), 39-59.

Stoszkowski, J., & Collins, D. (2016). Sources, topics and use of knowledge by coaches. *Journal of Sports Sciences*, 34(9), 794-802. https://doi.org/10.1080/02640414.2015.1072279

Thomas, J. R., Nelson, J. K., & Silverman, S. J. (2012). *Métodos de pesquisa em atividade física* (6a ed.). Porto Alegre, RS: Artmed.

Walker, L.R., Thomas, R. & Driska, A.P. (2018). Informal and nonformal learning for sport coaches: a systematic review. *International Journal of Sports Science & Coaching*, 13(5), 694-707. https://doi.org/10.1177/1747954118791522

Winfield, J., Williams, J., & Dixon, M. (2013). The use of reflective practice to support mentoring of elite equestrian coaches. *International Journal of Evidence Based Coaching and Mentoring*, 11(1), 162-178. https://doi.org/10.1016/j.jveb.2012.12.056

Stroke placement in women's professional tennis: What's after the serve?

La colocación de los golpes en el tenis profesional femenino: ¿qué sigue luego del servicio?

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Abstract

The aim of the present study was to investigate the placement of the return, and the 3rd and 4th strokes in professional women's tennis, the possible differences related to the level of play and to derive practical recommendations from the results. In total this study contains an examination of 2562 returns, 2065 3rd strokes and 1606 4th strokes from 28 players in 19 professional women's tennis matches (WTA & ITF 2018-2020 season). All strokes were classified using a specific court division method taking outcome (i.e., in, out, net) and placements into account for statistical analyses. Results show that returns are mainly placed into the court's middle zones whereas 3rd strokes are placed more into offensive zone groups with 4th strokes similarly placed but more scattered. No correlation was found between the placement of the return and the 3rd stroke. Correlations were found between the placement of 4th stroke and the return, between the 4th and the 3rd stroke as well as between WTA and ITF players regarding all three strokes (return, 3rd stroke, 4th stroke). Present findings may be of interest to female tennis players and their coaches aiming to improve practice patterns in training and competitive performance in matches.

Keywords: *game opening – coaching – court division – return – target zones.*

Resumen

El objetivo del presente estudio fue investigar la colocación de la devolución, el tercer golpe y el cuarto golpe en el tenis profesional femenino, así como las posibles diferencias relacionadas con el nivel de juego y, finalmente, derivar recomendaciones prácticas a partir de los resultados. En total, este estudio contiene el examen de 2562 devoluciones, 2065 terceros golpes y 1606 cuartos golpes de 19 partidos de tenis profesional femenino de 14 jugadoras (tanto de la WTA como de la ITF) entre los años 2018 y 2020. Todos los golpes se clasificaron usando un método específico de división de la cancha que tiene en cuenta el resultado (es decir, *in, out, net*) y las colocaciones para los análisis estadísticos. Los resultados muestran que las devoluciones se colocan principalmente en las zonas centrales de la cancha (66,7 %), mientras que los terceros golpes se colocan más en grupos de zonas ofensivas (es decir, zonas exteriores 58,1 %, zona exterior prohibida 72,6 % zonas C 28,7 %) y los cuartos golpes colocados de manera similar, aunque más dispersos. No se encontró ninguna correlación entre la colocación de la devolución y el tercer golpe ($r = 0,517$, $p = 0,085$). Se encontraron correlaciones entre la colocación del cuarto golpe y la devolución ($r = 0,653$, $p < 0,05$), entre el cuarto y el tercer golpes ($r = 0,961$, $p < 0,001$), así como entre jugadoras de la WTA y la ITF con respecto a los tres golpes (devolución $r = 0,818$, $p < 0,01$; tercer golpe $r = 0,942$, $p < 0,001$; cuarto golpe $r = 0,821$, $p < 0,01$). Los presentes resultados pueden ser de gran interés para las jugadoras de tenis y sus entrenadores con el fin de mejorar los métodos de práctica en el entrenamiento y el rendimiento competitivo en los partidos.

Palabras clave: *apertura del juego, zonas objetivo, devolución, división de la cancha, entrenamiento.*

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Introduction

The game opening is a crucial feature of tennis (Born, 1996). Not only does every point start with a serve and in most cases with a return, these two strokes also have a strong impact on the outcome of a match (Gillet et al., 2009; Ma et al., 2013). Previous research has shown that the mean rally length in tennis is between three to six strokes, depending on the surface (Born, 2017; Carboch et al., 2018; Fernandez-Fernandez et al., 2008; Weber et al., 2010; Weber & Born, 2012), the 3rd and 4th stroke of a rally can be added to the so-called extended game opening that consists of the first four strokes of a rally (Born, 2017; Weber & Born, 2012). Also, 50-70% of all points played in professional tennis, no matter if it is men´s or women´s tennis and which surface is played, are finished after an extended game opening (Born, 2017; Carboch et al., 2018; Weber et al., 2010; Weber & Born, 2012). While the serve is probably the most examined stroke or match situation in tennis, respectively (Elliot et al., 2013; Gillet et al., 2009; Grambow et al., 2020; Grambow et al., 2021; Klaasen & Magnus, 2014; Mecheri et al., 2016; Meffert et al., 2018; O'Donoghue & Brown, 2008; Vaverka et al., 2018; Weber & Born, 2012), there is far less research on the return and almost none on the 3rd and 4th stroke although experts claim that the importance of these strokes for a successful tennis player is undeniable (Born, 1996; Born, 2017; Brabenec, 2000; Crespo & Miley, 1998; Giffenig, 2013; Gillet et al., 2009; Klaus et al., 2017; Meffert et al., 2018; Schönborn, 2006 & 2012; Weber et al., 2010; Weber & Born, 2012).

According to the tactical principals of tennis, one of the factors for a successful stroke execution is the placement of the stroke (Crespo & Miley, 1998; Ferrauti et al., 2014) which can be used to (1) move the opponent sideways out of the court, (2) push the opponent back away from the baseline or (3) put the opponent under time pressure (Ferrauti et al., 2014; Tiley, 2002; Schönborn, 2012). The placement into certain zones of the court is useful to execute these goals, whereas a misplaced stroke (e.g., central and short) can lead to an offensive situation for the opponent and put the player itself under pressure. For a systematic analysis of the stroke placement several court divisions have been established until today (Born, 2017; Giffenig, 2013; Gillet et al., 2009; Molina, 1995; Nowak & Panfil, 2012; Schönborn, 2008 & 2012; Tiley, 2002).

While most research on the return focuses primarily on performance indicators other than placement like winning percentages or winning outcome (Cui et al., 2018; Hizan et al., 2011; Ma et al., 2013; Merghes et al., 2014), contact point or ball trajectories (Reid et al., 2016) or efficiency (Filipcic et al., 2015), only a few references can be found for the placement of the return; additionally, all of them refer to men's tennis: Gillet et al. (2009) state that 75.5% of all returns in men's tennis are aimed to the central zone of the court and that aiming there leads to a higher winning percentage than aiming to outer zones. According to de Witt (2019) 67% to 92% of the returns on the ATP Tour are played through the middle of the court depending on the serve direction. Nowak and Panfil (2012) present similar findings while Hedelund and Rasmussen (1997) provide coaching tips by advising to aim the return to the middle and/or crosscourt.

Previous research from men's professional tennis for the 3rd and 4th stroke shows that approximately 80% are placed longer than the service line and 30% into the zones close to the baseline. The so-called forbidden zone (FZ) which is located in the center of the court and is related to strokes that are easy to return for the opponent is played into 30% of the time, making it 70% of all 3rd and 4th strokes placed outside the FZ. 60-70% of all 3rd and 4th strokes are placed into the zones close to the sidelines. Most of these strokes – approximately 30% of all strokes – are placed into the zones close to the sidelines directly behind the service line, referred to as C-Zones by Born (2017; Schönborn, 2008 & 2012). The difference between the two strokes can be described as the 3rd stroke being more precise than the 4th, meaning being placed more frequent into the latter described zones, the zones on the sideline, the zones close to the baseline as well as outside the FZ. Other research on the 3rd stroke focused on the position of the player and the error- and winner-rate (Klaus et al., 2017). Brabenec (2000) states that players should try to dominate the point with a fast and well-placed 3rd stroke but does not state any specific placement or target zones. Nowak and Panfil (2012) state that strokes to win points are directed to the outer zones of the court.

In contrast, there is a clear research gap regarding the mentioned strokes in women's tennis. Thus, to the best of the authors' knowledge, the present study is the first which examines the placement of the three strokes after the serve in women's professional tennis. In particular, this study tries to answer the following questions:

(1) Into which zones and zone groups of the court do professional women's tennis players place their (a) return (b) 3rd stroke and (c) 4th stroke?

(2) Can differences be observed between the placement of the three strokes?

(3) Can possible differences in the stroke placement be related to the level of play?

The main goal of the present study is to generate a first overview of the stroke placement in women's professional tennis. This could offer useful numbers for coaches and players to derive practical recommendations as well as being a starting point for following research.

Materials and Methodology

Participants: The research material consists of data from 19 professional women's tennis matches in total: 7 at the WTA Premier Mandatory[1] Tournament Mutua Madrid Open 2019, 5 at the WTA Premier 5[2] Tournament Internazionali BNL d'Italia 2019 as well as 7 matches from $15,000 and $25,000 ITF[3] Tournaments from 2018, 2019 and 2020. The 14 players examined at the WTA tournaments had a mean ranking at the end of the year 2019 of position 15.2 ± 14.4 with a mean age of 25.8 ± 3.1 years. The 14 players examined at the ITF tournaments had a mean ranking at the time of the tournaments of position 586.6 ± 291.3 with a mean age of 21.3 ± 5.1 years. These matches were chosen to get an overview of professional women's tennis and to show possible similarities and differences between different playing levels. Inferring from these numbers hereinafter the WTA players are referred to as the better players within the sample. In total this study contains examination of 2562 returns (1647 of the WTA players, 915 of the ITF players), 2065 3rd strokes (1317 WTA, 748 ITF) and 1606 4th strokes (1021 WTA, 585 ITF).

Design & Procedures: Matches examined in this study were recorded digitally and watched on a laptop using the VLC Media Player. Matches were allocated among three well trained observers on pre-defined criteria (specific zones, see figure 1) according to standard procedures as follows: Every return, 3rd and 4th strokes were observed regarding the outcome (i.e., in, out or net) and the placement (e.g., into zone 1c). Microsoft Excel was used to collect the observed data.

For the observation of the placement a modified court division method using 12 different zones based on Born (2017) was used (figure 1). This court division has the purpose of dividing the court as close-meshed as possible to guarantee a differentiated analysis of the stroke placement and, at the same time, keep the court division simple enough to make it applicable for coaches and players (Born, 2017). For the purpose of this study the original division into 14 zones was modified by setting aside the zones 5a and 5b, located directly at the net, because data shows that less than 2% of all strokes are placed into these zones (Born, 2017). Instead, the zones 3a, 3b, 4a and 4b, originally located between service line and the zones 5a and 5b, were enlarged up to the net. All in all, the area between the service line and the net is divided lengthways into 4 equally sized zones (3a, 3b, 4a, 4b) while the area between the service line and the baseline is divided lengthways the same way and additionally across in two parts which results in 8 equally sized zones (1a-d, 2a-d). Also based on Born (2017) certain zones are combined into zone groups to get a better overview: Zones 1c and 2c form the zone group *C-Zones*; zones 1a, 1b, 2a, 2b form *Baseline*; zones 1a-d, 2a-d form *Longer than serviceline*; zones 1d, 2d, 3b, 4b form *Forbidden Zone (FZ)*; zones 1a-c, 2a-c, 3a, 4a form *Outside FZ*; zones 1b, 1d, 2b, 2d, 3b, 4b form *Middle Zones* and zones 1a, 1c, 2a, 2c, 3a, 4a form *Outer Zones*. The collected data was edited in Microsoft Excel for Mac. Since only video footage of professional players, resulting in publicly open-access data, was used, no approval of the ethics committee was necessary.

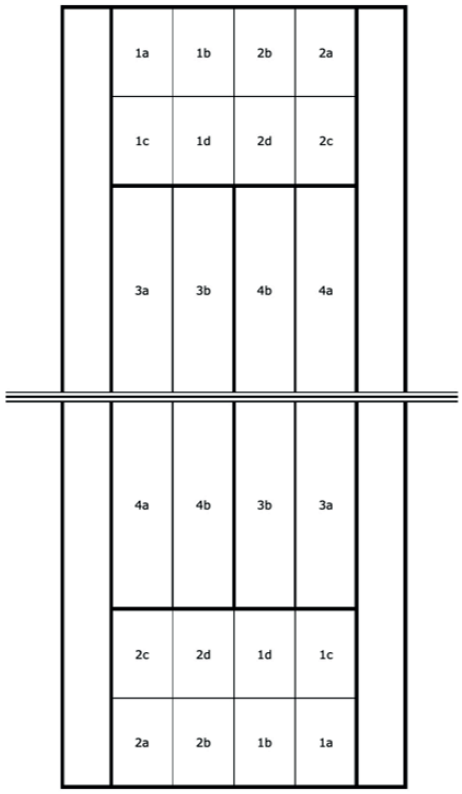

Figure 1. Modified court division used for this study based on Born (2017).

Analysis: The collected data were first sorted in Microsoft Excel for Mac to get an overview. The statistical analyses were carried out using IBM SPSS Statistics 27 (SPSS Inc., Chicago, Illinois, USA). First the Chi square test was computed to test for equal distribution. Second the Chi square test of independence was used to test for a relationship between stroke (i.e., return, 3rd, 4th) and placement frequency (i.e., different zones).

Correlations between the three strokes as well as between the level of play (i.e., WTA, ITF) were computed using Spearman`s rank correlation. The level of significance was set to $p < .05$ and if applicable to $p < .01$ and $p < .001$.

Results

Main findings show that female pro tennis players hit their returns most frequently into the zones 2d

1 WTA: Women's Tennis Association. This tournament category is the 2nd highest after the Grand Slam tournaments in women's professional tennis.
2 This tournament category is the 3rd highest after the Grand Slam and the Premier Mandatory tournaments in women's professional tennis
3 ITF: International Tennis Federation. The examined tournaments are the lowest categories of professional tournaments in women's tennis.

(18.9%), 1d (14.0%), 2b (11.6%) and 1b (10.3%), 66.7% into the middle zones, 82.4% longer than the service line and 33.6% into the zones at the baseline. Further, their 3rd strokes were hit into the zones 2c (16.7%), 2d (12.2%), 1c and 2a (both 12.0%) most frequently, 28.7% into the C-Zones, 84.8% longer than the service line and 35.8% into the zones at the baseline and 72.6% outside the FZ. Their 4th strokes were targeted most frequently into 2c (15.0%), 2d (12.6%), 2a (11.4%), 1d (9.9%) and 1c (9.7%), 24.7% go into the C-Zones, 83.4% longer than the service line, 36.3% into the zones at the baseline as well as 68.5% outside the FZ.

Details on descriptive findings for the return are presented in table 1, for the 3rd stroke in table 2 and for the 4th stroke in table 3.

Chi square test revealed an unequal distribution between the number of strokes to the different zones (*p* < *.001*) which means that the ball placement was different in every zone of the court (see table 1-3). Chi square test of independence showed significant relationships between the respective stroke (return, 3rd, 4th) and the placement frequency into the different zones (x^2 *(df) = 22, p < .001, Cramer-V .162*).

Table 1.
Return WTA & ITF Players.

CATEGORY	SUBCATEGORY	RETURN TOTAL	RETURN ITF	RETURN WTA
n =		2562	915	1647
Result	in (%)	83.4%	84.4%	82.8%
n =		2136	772	1364
Zones	1a	5.3%	6.3%	4.7%
	1b	10.3%	6.6%	12.5%
	1c	6.9%	9.1%	5.7%
	1d	14.0%	12.7%	14.8%
	2a	6.4%	6.0%	6.7%
	2b	11.6%	11.5%	11.6%
	2c	8.9%	12.4%	7.0%
	2d	18.9%	18.4%	19.2%
	3a	2.3%	3.2%	1.8%
	3b	5.4%	4.4%	6.0%
	4a	3.4%	3.6%	3.2%
	4b	6.4%	5.7%	6.8%
Zone	C-Zones	15.9%	21.5%	12.7%
Groups	Baseline	33.6%	30.4%	35.4%
	Longer than service line	82.4%	83.0%	82.1%
	FZ	44.8%	41.2%	46.8%
	Outside FZ	55.2%	58.8%	53.2%
	Middle Zones	66.7%	59.3%	70.8%
	Outer Zones	33.3%	40.7%	29.1%

Table 2.
3rd Stroke WTA & ITF Players.

CATEGORY	SUBCATEGORY	3rd STROKE TOTAL	3rd STROKE ITF	3rd STROKE WTA
n =		2065	748	1317
Result	in (%)	85.5%	85.3%	85.6%
n =		1765	638	1127
Zones	1a	9.3%	9.6%	9.1%
	1b	6.3%	6.3%	6.3%
	1c	12.0%	13.5%	11.2%
	1d	8.0%	7.5%	8.3%
	2a	12.0%	14.7%	10.5%
	2b	8.2%	7.4%	8.7%
	2c	16.7%	17.6%	16.2%
	2d	12.2%	11.3%	12.8%
	3a	3.7%	3.1%	4.0%
	3b	3.4%	1.6%	4.4%
	4a	4.4%	4.1%	4.5%
	4b	3.8%	3.4%	4.0%
Zone	C-Zones	28.7%	31.0%	27.4%
Groups	Baseline	35.8%	37.9%	34.6%
	Longer than service line	84.8%	87.8%	83.1%
	FZ	27.4%	23.8%	29.5%
	Outside FZ	72.6%	76.2%	70.5%
	Middle Zones	41.9%	37.5%	44.5%
	Outer Zones	58.1%	62.5%	55.5%

Table 3.
4th Stroke WTA & ITF Players.

CATEGORY	SUBCATEGORY	4th STROKE TOTAL	4th STROKE ITF	4th STROKE WTA
n =		1606	585	1021
Result	in	84.6%	85.3%	84.2%
n =		1359	499	860
Zones	1a	8.8%	11.0%	7.6%
	1b	7.5%	6.2%	8.3%
	1c	9.7%	11.6%	8.6%
	1d	9.9%	6.2%	12.0%
	2a	11.4%	12.0%	11.0%
	2b	8.5%	9.4%	8.0%
	2c	15.0%	17.0%	13.8%
	2d	12.6%	11.8%	13.0%
	3a	3.5%	3.0%	3.7%
	3b	4.3%	2.8%	5.2%
	4a	4.0%	4.4%	3.8%
	4b	4.7%	4.4%	4.9%
Zone	C-Zones	24.7%	28.7%	22.4%
Groups	Baseline	36.3%	38.7%	34.9%
	Longer than service line	83.4%	85.4%	82.3%
	FZ	31.5%	25.3%	35.1%
	Outside FZ	68.5%	74.7%	64.9%
	Middle Zones	47.5%	40.9%	51.4%
	Outer Zones	52.5%	59.1%	48.6%

The results of the Spearman`s rank correlations are displayed in figure 2. They showed significant correlations between the placement of the 3rd and 4th stroke ($p < .001$) as well as between the return and the 4th stroke ($p < .05$). There was no significant correlation between the return and the 3rd stroke. Also, significant correlations were shown between the WTA and ITF players regarding all three strokes (return $p < .01$; 3rd stroke $p < .001$; 4th *stroke* $p < .01$).

Discussion

This study aimed to examine the placement of the return, 3rd and 4th stroke in professional women's tennis in general and also possible differences related to the level of play.

The difference between strokes (i.e., return, 3rd, 4th) revealed different placement frequencies into the respective 12 zones of the court. However, significant correlations between the return and 4th stroke as well as between the 3rd and 4th stroke indicate a similar distribution of these strokes into the respective 12 zone. However, the return and the 3rd stroke data were not inspected since there was no significant correlation between these two strokes. Also, the significant correlation between WTA and ITF players regarding all three strokes indicate that the two groups place the respective strokes with the same distribution into the 12 zones.

Return: The four most frequently targeted zones of the return (2d, 1d, 2b, 1b) are all located behind the service line in the middle part of the court and accumulate 54.9% of all returns and even 66.7% when adding the shorter middle zones 3b and 4b. Also, the returns tend to go more to the backhand side – of a right-handed opponent – with zone 2d being the most frequented zone and all zones on this side of the court being more frequented than their counterparts on the forehand side of a right-handed player. This is in line with previous research findings regarding the return, which suggest players to aim more often to the backhand side to avoid the presumably better forehand of the opponent (de Witt, 2019; Gillet et al., 2009; Hedelund & Rasmussen, 1997; Nowak & Panfil, 2012).

Alongside a correlation between WTA and ITF players regarding their return placement, some differences seem noteworthy: WTA players place their returns longer and more frequent to the middle zones compared to ITF players; however, this striking feature failed statistical significance. Still, the middle zones and especially those closer to the baseline are recommendable targets for the return derived from this data.

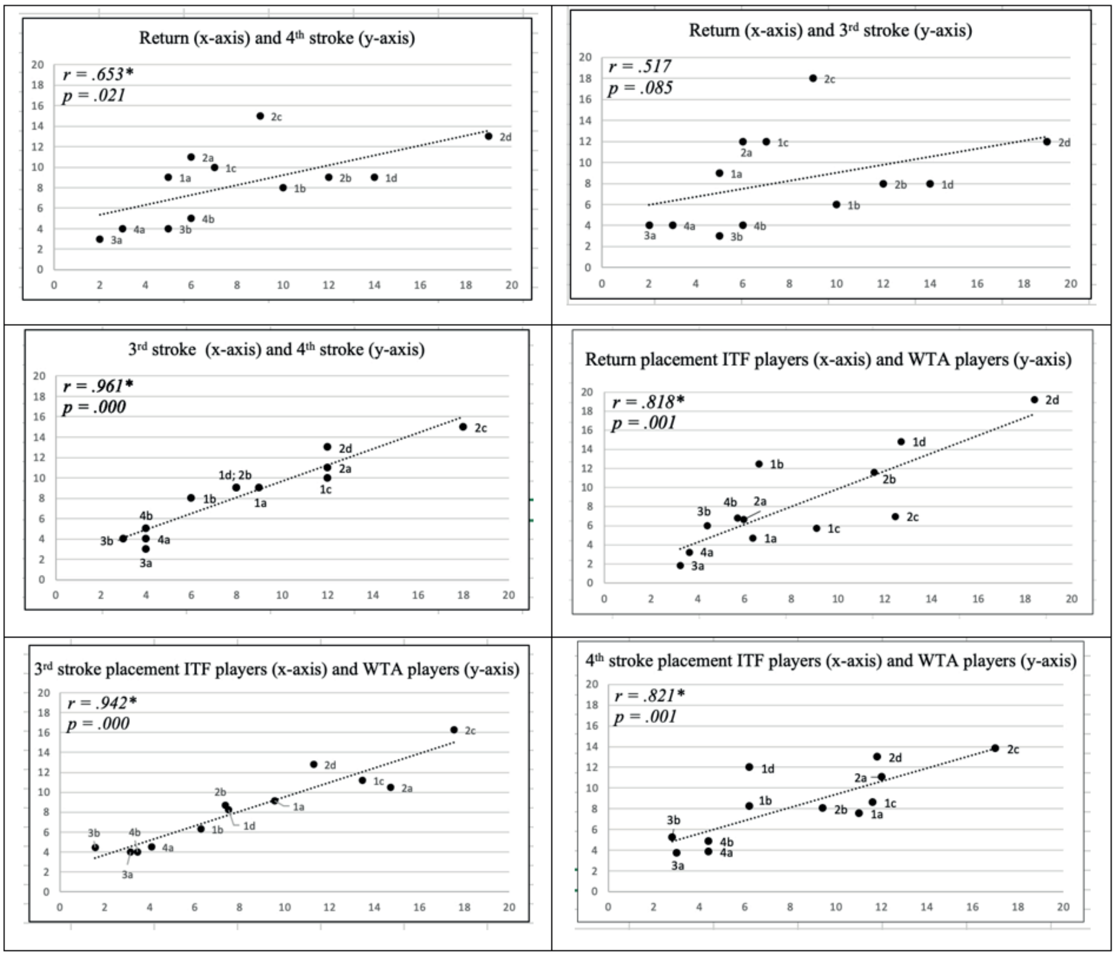

Figure 2. Spearman`s rank correlations for stroke placement regarding respective zones.

3rd Stroke: The placement of the 3rd stroke is mostly in line with the data from men's professional tennis (Born, 2017; Nowak & Panfil, 2012; Schönborn, 2008) but also shows some differences. ATP players surpass the women regarding the C-Zones, the Outside FZ and Outer Zones while women are playing close to the baseline more often. Based on this, ATP players seem to play more angles and move the opponent more to the sides of the court while women tend to play the 3rd stroke deeper but less often to the sidelines. A possible explanation could be the overall more aggressive and offensive return of female players in comparison to male players which makes it more challenging to play an offensive 3rd stroke.

However, following the numbers for the C-Zones, Outer-Zones and Outside FZ (see table 2) the data from this study meets the intention of the serving player to move the opponent and indicates an overall offensive character of most of the 3rd strokes (Born, 2017; Brabenec, 2000; Crespo & Miley, 1998; Nowak & Panfil, 2012). This is also the main difference to the return placement which is by far more frequent to the middle zones, possibly explaining missing correlations between these two strokes.

Although there is a significant correlation between WTA and ITF players regarding the 3rd stroke, every zone group related to an offensive tactic (C-Zones, Baseline, Longer than service line, Outside FZ, Outer Zones) is targeted more often by ITF players while both player groups hit the same percentage of 3rd strokes in. With this, it seems reasonable that a lower return quality on the ITF level (less long and less into the middle zones) may lead to an offensive situation for the 3rd stroke more often. Thus, the recommendation derived from this data is to try and place the 3rd stroke at least longer than the service line or even either into the baseline zones or into the C-Zones.

4th Stroke: All in all, the placement of the 4th stroke is comparable to the placement of the 3rd stroke as the returning player seems to have the same placement intentions when hitting the 4th stroke as the serving player when hitting the 3rd stroke.

Although correlating, the WTA and ITF players' 4th stroke placement differs marginally. Quite surprisingly at first sight, ITF players hit, similar to the findings regarding the 3rd stroke, more often into the offensive zone groups than WTA players (see table 3). A second look triggers an attempt to explain this by a still overall lower quality of the 3rd stroke of ITF players in comparison to the WTA players in spite of the placement. This suggests – and underlines the obvious – that stroke placement is just one factor that defines the quality of a stroke and its effect on an opponent. Other factors being stroke velocity, stroke timing and spin.

All in all, the recommendation derived from this data for the placement of the 4th stroke is the same as for the placement of the 3rd stroke whilst always depending on the situation the player is in.

Although previous research reported differences between men's and women's tennis regarding the game opening with respect to i.e., winning percentages (Carboch, 2017; Hizan et al., 2011), the present findings on stroke placement support previous research on men's tennis.

Conclusion

The present study aimed to investigate the placement of the return, 3rd and 4th stroke in professional women's tennis, find possible differences related to the level of play and derive practical recommendations from the findings.

In line with previous research (de Witt, 2019; Gillet et al., 2009; Hedelund & Rasmussen, 1997; Nowak & Panfil, 2012), findings show that the return is mainly placed to the middle zones of the court (66.7%) with a tendency of being directed more to the backhand side of a right-handed opponent, most frequented in zone 2d (18.9%). With the return and 3rd stroke not correlating, the 3rd stroke is placed less central than the return but more to offensive zone groups such as Outside FZ 72.6%, most frequented in 2c (16.7%) which specifies previous reports (Born, 2017; Nowak & Panfil, 2012; Schönborn, 2008). The return and 4th stroke as well as the 3rd and 4th stroke, however, correlated with the 4th stroke being more scattered, again most frequently into zone 2c (15.0%). Further, WTA and ITF players correlate regarding their placement of all strokes (i.e., return, 3rd and 4th stroke), indicating no difference regarding the level of play (rankings: WTA 15.2 ± 14.4, ITF 586.6 ± 291.3).

The present findings may serve women and men tennis players and their coaches to better understand the placement of the different strokes in the extended game opening.

Building on that they can use this knowledge to improve their on-court practice by practicing with certain target zones for each stroke. Also, players can improve their competitive performance by having clear target areas for their own strokes and the knowledge where the opponents' strokes most probably will land.

However, future research may further address presumable correlations between placement and (direct) success as well as stroke placement in different tactical situations. Since the present data didn`t allow differentiation between points after 1st or 2nd serve and the placement of all three examined strokes probably is dependent of the quality of the preceding serve, the difference between points starting with a 1st or 2nd serve is of highest interest for future research.

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References

Born, H.-P. (1996). Aufschlag und Return. *Deutsche Tennis-Zeitung*, 50 (9), 64-65.

Born, P. (2017). *Systematische Analyse der erweiterten Spieleröffnung des Aufschlägers im Herrentennis der Weltspitze inklusive Ableitung anwendungsorientierter Trainingsformen*. Dissertation, Deutsche Sporthochschule Köln.

Brabenec, J. (2000). A serious look at second shots. *ITF Coaching and Sport Science Review*, 20, 13-14.

Carboch, J. (2017). Comparison of game characteristics of male and female tennis players at grand-slam tournaments in 2016, *TRENDS in Sport Sciences*, 4 (24), 151-155.

Carboch, J., Placha, K. & Sklenarik, M. (2018). Rally pace and match characteristics of male and female tennis matches at the Australian Open 2017, *Journal of Human Sport and Exercise*, 13(4), 743-751.

Crespo, M. & Miley, D. (1998). *Advanced Coaches Manual*. London: The International Tennis Federation, ITF Ltd.

Cui, Y., Gómez M.-A., Gonçalves, B. & Sampaio, J. (2018). Performance profiles of professional female tennis players in grand slams. *PLoS ONE 13*.

De Witt, J. (2019). Portrait und Interview Jan de Witt – Individuelles Training nach Daten, *tennisSPORT*, 4, 6-13.

Elliot, B., Whiteside, D., Lay, B. & Reid, M. (2013). The female tennis serve: An analogous version of the male serve. In: *31st International Society of Sports Biomechanics Conference*. Taipei, 7-11.

Fernandez-Fernandez, J., Sanz-Rivas, D., Fernandez-Garcia, B. & Mendez-Villanueva, A. (2008). Match activity and physiological load during a clay-court tennis tournament in elite female players. *Journal of Sports Science*, 26 (14), 1589-1595.

Ferrauti, A., Maier, P. & Weber, K. (2014). *Handbuch für Tennistraining* (3. überarb. und erw. Auflage von Tennistraining). Aachen: Meyer & Meyer.

Filipcic, A., Zecic, M., Reid, M., Crespo, M., Panjan, A., & Nejc, S. (2015). Differences in performance indicators of elite tennis players in the period 1991-2010. *Journal of Physical Education and Sport*, 15(4), 671.

Giffenig, E. (2013). *Developing High Performance Tennis Players*. Stuttgart: Neuer Sportverlag.

Gillet, E., Leroy, D., Thouvarecq, R. & Stein, J.-F. (2009). A national analysis of elite tennis serve and serve-return strategies on slow surface. *Journal of Strength and Conditioning Research*, 23 (2), 532-539.

Grambow, R., O'Shannessy, C., Born, P., Meffert, D., & Vogt, T. (2020). Serve efficiency developments at Wimbledon between 2002 and 2015: a longitudinal approach to impact tomorrow's tennis practice. *Human Movement*, 21(1), 65-72.

Grambow, R., O`Shannessy, C., Born, P., Meffert, D., and Vogt, T. (2021). Serve efficiency development indicates an extended women's tennis world class cohort: Analysing 14 years of Ladies Wimbledon Championships – implications for coaching. *Human Movement*, 2 (22).

Hedelund, C.E. & Rasmussen, A. (1997). Serve and return tactics. *ITF Coaching and Sport Science Review*, 13, 6-8.

Hizan, H., Whipp, P. &Reid, M. (2011). Comparison of serve and serve return statistics of high performance male and female tennis players from different age-groups. *International Journal of Performance Analyses in Sport*, 11, 365–375.

Klaasen, F. & Magnus, J. (2014). *Analyzing Wimbledon: The Power of Statistics*. Oxford University Press.

Klaus, A., Bradshaw, R., Young, W., O'Brien, B. & Zois, J. (2017). Success in national level junior tennis: Tactical perspectives. *International Journal of Sport Science and Coaching*, 12, 618–622.

Ma, S. M., Liu, C. C., Tan, Y., & Ma, S. C. (2013). Winning matches in Grand Slam men's singles: an analysis of player performance-related variables from 1991 to 2008. *Journal of Sports Science*, 31(11), 1147-1155.

Mecheri, S., Rioult, F., Mantel, B., Kauffmann, F. & Benguigui, N. (2016). The serve impact in tennis: First large-scale study of big Hawk-Eye data. *Statistical Analysis and Data Mining: The ASA Data Science Journal*, 9(5), 310-25.

Meffert, D., O'Shannessy, C., Born, P., Grambow, R. & Vogt, T. (2018). Tennis serve performances at break points: Approaching practice patterns for coaching. *European Journal of Sport Science*, 18 (8), 1151-7.

Merghes, P. E., Simion, B., Nagel, A. (2014). Comparative Analysis of Return of Serve as Counter-attack in Modern Tennis. *Timisoara Physical Education and Rehabilitation Journal*, 6 (12), 18-22.

Molina, I. (1995). The comprehensive coaching system: Some Examples of Drills. *ITF Coaching and Sport Science Review*, 7, 1-2.

Nowak, M. & Panfil, R. (2012). Scoring abilities in the game of tennis – a pragmatic study of unique cases, *Human Movement*, 13 (4), 313-322.

O'Donoghue, P. & Brown, E. (2008). The Importance of Serve in Grand Slam Singles Tennis. *International Journal of Performance Analysis in Sport*, 8 (3), 70-8.

Reid, M., Morgan, S. & Whiteside, D. (2016). Matchplay characteristics of Grand Slam tennis: implications for training and conditioning, *Journal of Sport Science*, 34(19), 1791-1798.

Schönborn, R. (2006). *Optimales Tennistraining.* Balingen: Spitta.

Schönborn, R. (2008). *Tennis Techniktraining* (3. überarb. Auflage). Aachen: Meyer & Meyer.

Schönborn, R. (2012). *Strategie + Taktik im Tennis*. Gelnhausen: Wagner.

Tiley, C. (2002). A winning game plan for all-court players. *ITF Coaching and Sport Science Review*, 27, 7-9.

Vaverka, F., Nykodym, J., Hendl, J., Zhanel, J. & Zahradnik, D (2018). Association between serve speed and court surface in tennis. *International Journal of Performance Analysis in Sport*, 18 (2), 262-72.

Weber, K. & Born, P. (2012). Die besondere Bedeutung der erweiterten Spieleröffnung im Leistungstennis. *Leistungssport*, 6, 26-32.

Weber, K., Exler, T., Marx, A., Pley, C., Röbbel, S. & Schäffkes, C. (2010). Schnellere Aufschläge, kürzere Ballwechsel und höherer Zeitdruck für Grundschläge in der Tennis-Weltspitze. *Leistungssport*, 5, 36-42.

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Placement of inertial measurement units in Racket Sports: Perceptions of coaches for IMU use during training and competition.

Colocación de unidades de medición inercial en los deportes de raqueta: percepciones de los entrenadores sobre el uso de IMU durante el entrenamiento y la competencia.

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Abstract

While inertial measurement units (IMU) have become an integral part of sports performance analysis, upper body-mounted IMUs have been found to exhibit poor reliability in measuring lower-limb loading. In racket sports, IMUs have been placed in a number of positions on the upper body, lower body and racket in a research setting. A potential limitation to the concurrent use of multiple IMUs is that coaches may be reluctant to allow their athletes to wear the units during training and competition due to concerns that the units would interfere with athlete movement. This study seeks to understand the perceptions of racket sports coaches towards the use of IMUs in training and competition. A total of 58 racket sport coaches responded to a survey on the use of IMUs during training and competition. Based on the responses, 96.6% (56 out of 58) of coaches indicated that they would allow their athletes to wear IMUs in training, while 65.5% (38 out of 58) would allow their athletes to wear IMUs during competition. For use in training, 9 of the 14 suggested IMU placements received significant positive responses. However, none of the suggested IMU placements received significant positive responses for use during competition and 11 of the 14 received significant negative responses. This suggests that coaches understand the benefits of collecting data from IMUs during competition there remains concern regarding inconvenience to the athlete, lack of comfort, and appearance. Despite this, for use in training, a number of upper and lower body-mounted IMUs placements have the potential to be part of regular monitoring in racket sports.

Keywords: *badminton, table tennis, tennis, squash, Inertial Measurement Units.*

Resumen

Aunque las unidades de medición inercial (IMU, por su sigla en inglés) se han convertido en una parte integral del análisis del rendimiento deportivo, se ha descubierto que las IMU colocadas en la parte superior del cuerpo presentan poca fiabilidad en cuanto a la medición de la carga de las extremidades inferiores. En los deportes de raqueta, las IMU se han puesto en varias posiciones en la parte superior del cuerpo, la parte inferior y la raqueta en un entorno de investigación. Una posible limitación para el uso simultáneo de múltiples IMU es que

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los entrenadores pueden ser reacios a permitir que sus atletas lleven las unidades durante el entrenamiento y la competencia debido a la preocupación de que las unidades interfieran con el movimiento del atleta. Este estudio pretende conocer las percepciones de los entrenadores de deportes de raqueta frente al uso de las IMU en el entrenamiento y la competencia. Un total de 58 entrenadores de deportes de raqueta respondieron una encuesta sobre el uso de las IMU durante el entrenamiento y la competencia. A partir de las respuestas, el 96,6 % (56 de 58) de los entrenadores indicó que permitirían a sus atletas llevar las IMU en el entrenamiento, mientras que el 65,5 % (38 de 58) permitiría a sus atletas llevar las IMU durante la competencia. Para su uso durante el entrenamiento, 9 de las 14 colocaciones de IMU sugeridas recibieron respuestas positivas significativas. Sin embargo, ninguna de las ubicaciones de IMU sugeridas recibió respuestas positivas significativas para su uso durante la competencia, y 11 de las 14 recibieron respuestas negativas significativas. Esto sugiere que, si bien los entrenadores entienden los beneficios de la recopilación de datos de las IMU durante la competencia, sigue habiendo preocupaciones respecto a inconvenientes para el atleta, falta de comodidad y apariencia. A pesar de esto, para su uso durante el entrenamiento, varias colocaciones de IMU puestas en la parte superior e inferior del cuerpo tienen el potencial de ser parte de un monitoreo regular en los deportes de raqueta.

Palabras clave: *bádminton, tenis de mesa, tenis, squash, Unidades de Medición Inercial .*

Introduction

The use of micro-technology has become an integral part of sports performance analysis, with the majority of the commercially-available micro-technology units containing inertial measurement units (IMUs) (Chambers et al., 2015). IMUs normally comprise three gyroscopes, three accelerometers and magnetometers, providing rate of turn, linear acceleration and magnetic field data respectively but also orientation calculated based on a fusion of these signals (Baca et al., 2009). IMUs are light, portable, inexpensive, easy to set up and allow for rapid evaluation of a large number of athletes (Picerno et al., 2011). IMUs allow athletes to perform normal movements with little encumbrances in their normal training environment rather than in a sports science or biomechanics laboratory (Zok, 2014). IMUs also provide a means to obtain movement data for indoor, court-based sports. The use of IMUs avoid many of the limitations of video-based time-motion analysis, such as challenges with line of sight, inconsistent inter-operator reliability (Barris & Button, 2008), time consuming marking up of individuals and labour-intensiveness of data collection (Dobson & Keogh, 2007); and GPS which has limitations of accurately assessing movement in court-based sports (Duffield et al., 2010) and an inability to be used in an outdoor setting without sufficient satellite coverage (Dellaserra et al., 2014). Therefore, it is possible that IMUs could offer a significant advantage for the collection of data associated with indoor court based movement.

Player load is a commonly measured metric in sport athletes as a method to quantify training and match play. Catapult Innovations (Melbourne, Australia) developed the modified vector magnitude parameter called “Player Load” by integrating accumulated data from triaxial accelerometers within the MinimaxX (Catapult Innovations. Scoresby, Victoria, Australia) units (Boyd et al., 2011). The Player Load calculation has been used across a range of team sports (Fox et al., 2018) and has since been applied in racket sports, including Badminton (Abdullahi et al., 2019) and Tennis (Galé-Ansodi et al., 2016). Outside of training load monitoring, peak accelerations from upper body-mounted IMUs have been used to assess injury risk in athlete populations. For example, in a study of Cricket fast bowlers, faster time to peak accelerations were found to differentiate between athletes with and without lower back pain (Senington et al., 2020).

However, upper body-mounted IMUs have been shown to exhibit poor reliability and poor validity when compared to motion analysis and force platform data (Edwards et al., 2019). As upper body-mounted IMUs are positioned further away from the point of ground contact, the impact forces are dissipated through the joints and body tissues between the foot and the IMU, resulting in a loss of validity (Glassbrook et al., 2020b). In Badminton, Player Load and relative distance derived from an upper body-mounted IMU only correlated to the heart-rate measures at the High Intensity zone and not for the Low or Medium Intensity zones, with the latter showing a negative correlation in both cases (Abdullahi et al., 2019). The overall high work density observed in Badminton compared to field-based sports makes it difficult to observe clear differences in the Low and Medium Intensity zones. In a separate study, a low correlation was found between player load data obtained from an upper body-mounted IMU and differential ratings of perceived exertion (RPE) at the lower limbs (Wylde et al., 2019). Therefore, the consideration as to whether the upper body is the ideal location for IMU placement depends on a critical understanding of what information can be obtained from a specific sensor location.

IMUs worn directly on the lower limb (tibia) and shoes have been utilised in Rugby League to measure accelerations during sprinting (Glassbrook et al., 2020a) and to assess lower limb asymmetry (Glassbrook et al., 2020b). IMUs worn on the lower limbs are therefore able to measure forces more directly than units mounted on the upper body (Glassbrook et al., 2020a). In addition, tibia mounted IMUs have been found to provide good to excellent reliability for measurement of impact loading and step count during Football (Soccer) specific acceleration-deceleration, plant and cut and change of direction tasks (Burland et al., 2021).

Lower limb mounted IMUs may therefore provide a more direct measure of the forces and loads acting on the lower limbs in racket sports, which may have potential implications for injury management. In a study of elite Badminton players, lower limb injuries accounted for 43% of all injuries sustained over a 1-year period (Yung et al., 2007). In a separate study, 64% of injuries recorded in youth Badminton players were soft-tissue sprains and strains with knee injuries being the most common, accounting for 42% of injuries to the lower limbs (Goh et al., 2013). Therefore, monitoring specific anatomical regions of the body during sports like Badminton may offer anatomically focussed force and load information which could hold insights into injury prediction and rehabilitation targets.

Within racket sports (such as Badminton, Table Tennis and Tennis), IMUs have been utilised to quantify both lower body and upper body movements and assess forces and loads during training and competition. This has included the concurrent use of multiple IMUs and positioning of the IMUs at the wrist, ankle, lower leg, lower arm, upper arm, racket handle, racket head, upper back and lower back (see Table 1).

Table 1.
Placement of IMU in Racket Sports.

Sport	Wrist	Lower Leg	Hand	Lower Arm	Upper Arm	Racket Handle	Racket Head	Upper Back	Lower Back	Reference
Badminton								*		Abdullahi et al., 2019
Badminton							*			Anik et al., 2016
Badminton							*			Kiang et al., 2009
Badminton			*	*	*	*				Shan, Ming et al., 2015
Badminton	*				*					Shan, Sen et al., 2015
Badminton									*	Dieu et al., 2014
Badminton				*						Jacob et al., 2016
Badminton							*			Koon et al., 2005
Badminton				*						Raina et al., 2017
Badminton	*		*	*	*					Rusydi et al., 2015
Badminton								*		Sasaki et al., 2018
Badminton	*									Taha et al., 2016
Badminton	*	*								Wang et al., 2016
Badminton								*		Wylde et al., 2019
Badminton						*				Yu and Zhao, 2013
Table Tennis		*	*	*	*					Bańkosz & Winiarski, 2020
Table Tennis						*				Blank et al., 2015
Table Tennis						*				Boyer et al., 2013
Table Tennis	*									Guo et al., 2010
Tennis	*				*					Ahmadi et al., 2009
Tennis				*						Connaghan et al., 2011
Tennis								*		Galé-Ansodi et al., 2016
Tennis	*									Kos et al., 2016
Tennis	*									Whiteside et al., 2017
Tennis & Badminton	*									Anand et al 2017

Whilst sensor placement will be important and related to the area under investigation, the use of multiple IMUs could allow for some redundancy in the data collection. However, a potential limitation to the concurrent use of multiple IMUs is that coaches may be reluctant to allow their athletes to wear IMU units during training and competition. As collaboration between sport scientists and coaches is instrumental for the success of performance analysis systems (Hughes & Bartlett, 2002), a nuanced and symbiotic relationship between the sport scientist and the coach is required when planning data collection and developing performance analysis outputs (Bampouras et al., 2012). It is therefore important to consider the perception of coaches towards the specific technology when assessing the potential use of multiple IMUs for performance analysis and/or load monitoring.

To date there is a lack of research pertaining to the acceptance by coaches towards the use of wearable technology. In one of the few published studies in this area, 113 strength and conditioning (S&C) coaches and athletic trainers (AT) working within the National Collegiate Athletic Association (NCAA) and professional sport were surveyed on their opinions towards the use of wearable technologies (Luczak et al., 2020). In the pilot study of 25 S&C coaches and ATs, it was found that 76% reported a negative response to the use of wearable technologies, citing that wearables were not measuring what the practitioners needed and highlighting a significant lack of trust with existing wearables solutions. In the full study of 113 S&C coaches and ATs, 73% reported frustrations with wearable technologies due to inaccurate data, lack of meaningful recommendations and challenges in getting the technology to work consistently. Respondents also highlighted that athletes were reluctant to use wearable technologies due to the perceived lack of comfort, inconvenience, appearance and concerns that they are being tracked. To quote one coach, "wearables are fool's gold" (Luczak et al., 2020). This study highlights that regardless of the reliability and validity of wearable technologies, a lack of coach acceptance can negatively impact the use and adherence from athletes. Furthermore, this study was with a group of S&C coaches and ATs, who are potentially more accustomed to the use of wearable technology, meaning that the concerns raised could be amplified further when applied to sport specific coaches. Within this context, this study seeks to understand the perceptions of racket sports coaches towards the use of IMUs in racket sports training and competition.

Materials and methods

A sample of racket sport coaches was approached to complete an online survey relating to their perception of the use of IMUs in training and competition. Participants selected were those who indicated their primary job role (source of income) as a coach in either Badminton, Squash, Table Tennis or Tennis in their profile on the professional networking platform LinkedIn (LinkedIn Corporation, Mountain View, California, USA). Responses to blind surveys of coaches have been found to be low, for example 24.2% in a study of youth soccer coaches (Mawson et al., 2018), while quantitative surveys of coaches' perceptions have been published with a sample of 46 respondents (Wright et al., 2012). Therefore, a desired minimal sample size of 46 respondents was set for this study, with a larger pool of 140 coaches contacted and a response window set at 6 months.

Participants

A total of 140 coaches were contacted to complete the survey of which 41.4% (58) responded. Of the respondents, 44.8% (26) were Badminton coaches, 27.6% (16) were Table Tennis coaches, 18.9% (11) were Squash coaches, and 8.6% (5) were Tennis coaches. Of the respondents, 55.2% (32) classified themselves as coaching at an elite level, while 44.8% (26) classified themselves as coaching at a sub-elite level (either school, club or youth development). The respondents were from a total of 19 countries with Singapore (32.8%; 19) and the United Kingdom (13.8%; 8) having the highest number of respondents.

Procedure

The purpose of the survey was to ascertain the coaches' perspectives on the use of IMUs in training and competition. The key themes of the questions were as follows, with the full survey outlined in Table 2.

Demographic information: Participants were asked which sport they coached, the level at which they coached (elite, youth, club or school) and the country in which they resided.

Use of IMUs: IMUs shape, size and use were described and participants were asked if they would allow their athletes to wear IMUs in training and/or competition and, if yes, how many units they would allow their athletes to wear in training and competition respectively.

Placement of IMUs: Participants were asked if they would allow their athletes to wear IMUs at various locations on the body during training and/or competition. The suggested placements of the IMUs were based on the current literature, as highlighted in Table 1, with the addition of placement on the lower limbs and shoes (Glassbrook et al., 2020a; Burland et al., 2021), given the potential benefit of these approaches in a racket sport context.

Table 2.
Survey of Racket Sport Coaches on the use of Wearable Sensors during Training and Competition.

Questions	**Response Options**
Are you 21 years or above?	Yes No (if "No" then please do not continue with the survey)
Do you consent to your anonymous response being used in this study? (Note: Due to the anonymous nature of the survey, it will not be possible to delete your response once submitted.)	Yes No
What sport do you coach?	Badminton Squash Table Tennis Tennis Other
What level do you coach?	Elite Youth Development Club School
In which country do you reside?	Free Text
Would you be willing for your athlete to wear a sensor during training?	Yes No
Would you be willing for your athlete to wear a sensor during competition?	Yes No
What is maximum number of sensors you would be comfortable with your athlete wearing during training?	Free Text
What is maximum number of sensors you would be comfortable with your athlete wearing during competition?	Free Text
Would you willing for your athlete to wear a senor placed on the upper back?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the lower back?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the wrist (dominant)?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the wrist (non-dominant)?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the hand (dominant)?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the hand (non-dominant)?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the lower arm (dominant)?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the lower arm (non-dominant)?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the upper arm (dominant)?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the upper arm (non-dominant)?	Yes, in Training Yes, in Competition No

Table 2.
Survey of Racket Sport Coaches on the use of Wearable Sensors during Training and Competition (Continuation).

Would you willing for your athlete to wear a senor placed on the lower leg?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the shoe?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the racket handle?	Yes, in Training Yes, in Competition No
Would you willing for your athlete to wear a senor placed on the racket head?	Yes, in Training Yes, in Competition No

Analysis

The anonymous online survey was created via Google Forms (Google LLC, Mountain View, California, USA). The responses were downloaded as a Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA) file and exported into R (The R Foundation, Vienna, Austria) for processing and analysis. Given the categorical nature of the data, P values were calculated using the Chi-Squared test with alpha set at 0.05.

Results

Of the 58 racket sports coaches who completed the survey, a significant proportion, 96.6% (56), indicated that they would allow their athletes to wear IMUs in training (see Table 3). Overall, the median number of units that the coaches would allow their athletes to wear during training was two. Of the coaches who responded, 65.5% (38 out of 58) would allow their athletes to wear IMUs during competition. The median number of units that the coaches would allow their athletes to wear during competition was one.

Table 3.
Racket Sport Coaches Responses to the Use of IMUs and Number of Units in Training and Competition (Significance of p<0.05).*

Training				Competition			
No	**Yes**	**P value**	**Median**	**No**	**Yes**	**P value**	**Median**
2	56	<0.001*	2	20	38	0.013	1

For use in training, coaches were significantly more likely to agree to their athletes wearing IMUs positioned on the Upper Back, Lower Back, Dominant Wrist, Non-Dominant Wrist, Non-Dominant Lower Arm, Dominant Upper Arm, Lower Leg and Shoe (see Table 4). By contrast, for use in competition, coaches were significantly less likely to agree to their athletes wearing IMUs positioned on the Lower Back, Dominant Wrist, Dominant Hand, Non-Dominant Hand, Dominant Lower Arm, Non-Dominant Lower Arm, Dominant Upper Arm, Lower Leg, Racket Handle and Racket Head.

Discussion

The findings from this study demonstrate that a significant majority (96.6%) of racket sports coaches would allow their athletes to wear IMUs during training. A non-significant majority (65.5%) also indicated that they would allow their athletes to wear IMUs during competition. The median number of IMUs that the surveyed racket sports coaches would allow their athletes to wear was two during training and one during competition (see Figure 1).

Despite the majority of coaches who responded to the survey (65.5%) indicating that they would allow their athletes to wear IMUs during competition, this was not reflected in the responses regarding the positioning of the IMUs. In fact, only Non-Dominant Wrist showed an overall positive response (51.7%), while 11 of the proposed positions demonstrated significant negative responses from the coaches. While the coaches may have understood the benefits of data collected from wearable IMUs during competition, such as the ability to provide real-time feedback and reduced labour-intensiveness compared to video analysis (Chambers et al., 2015), when it came to considering the placement of IMUs at specific locations, concerns regarding inconvenience to the athlete, lack of comfort, and appearance may have become more apparent (Luczak et al., 2020). While this trade-off may have been deemed acceptable during training, it is clear that in competition, the majority of racket sport coaches were uncomfortable with allowing their athletes to use IMUs.

Table 4.
Racket Sport Coaches Responses to the Use of IMUs at Various Body and Equipment Positions in Training and Competition (Significance of p<0.05).*

	Training			Competition		
Placement	**No**	**Yes**	**P Value**	**No**	**Yes**	**P Value**
Upper Back	10	**48**	<0.001*	35	23	0.107
Lower Back	15	**43**	<0.001*	**43**	15	<0.001*
Dominant Wrist	17	**41**	0.001*	**44**	14	<0.001*
Non-Dominant Wrist	10	**48**	<0.001*	28	30	0.793
Dominant Hand	29	29	1.000	**51**	7	<0.001*
Non-Dominant Hand	25	33	0.289	**43**	15	<0.001*
Dominant Lower Arm	23	35	0.107	**48**	10	<0.001*
Non-Dominant Lower Arm	16	**42**	<0.001*	**42**	16	<0.001*
Dominant Upper Arm	21	**37**	0.029*	**49**	9	<0.001*
Non-Dominant Upper Arm	19	**39**	0.005*	**43**	15	<0.001*
Lower Leg	12	**46**	<0.001*	**43**	15	<0.001*
Shoe	11	**47**	<0.001*	36	22	0.058
Racket Handle	25	33	0.289	**48**	10	<0.001*
Racket Head	31	27	0.599	**49**	9	<0.001*

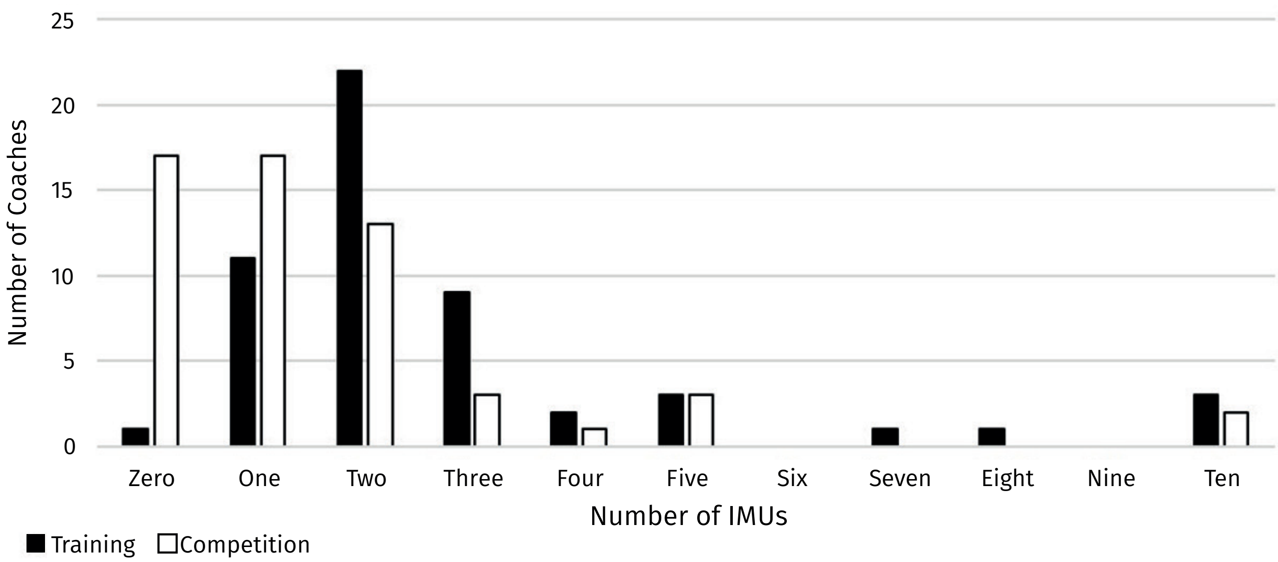

Figure 1. Maximum Number of IMUs Supported for Use During Training and Competition (Excluding Outliers Above 10 Units).

In a study of elite coaches' perspectives towards the use of technology, a number of potential challenges to the implementation of technology were identified (Jaswal, 2020). These included lack of athlete acceptance (36%), lack of support/acceptance from other coaches (27%) and concerns around losing subjectivity given an over-reliance on technology (27%). It is likely that these factors had an influence on the racket coaches' acceptance of the use of wearable IMUs during competition. For example, the perceived reluctance of an athlete to use the IMUs during competition may reduce the coaches' desire to adopt the technology. In the same study, the need to witness the concrete benefits and impact of technology was highlighted as a major factor in the coaches' decision to adopt a technology (Jaswal, 2020). While the surveyed racket sport coaches in the current study were informed that "the use of sensors can provide insights on the technical and tactical ability of the athletes", the lack of concrete evidence may have influenced the coaches' acceptance of the technology in the perceived higher-stakes competition environments. There is a perceived risk of wearing IMUs during competition, particularly as athletes may blame the technology for a poor performance (Luczak et al., 2020). Coaches would therefore require significant evidence of the benefits of the technology to performance, recovery or injury management before accepting this perceived risk during competition (Jaswal, 2020). Future studies are required to explore to what extent the adoption of wearable technology impacts performance, thus providing insights from which coaches and athletes can base these decisions.

A model of the five stages in the innovation-decision process (Rogers, 2003) highlights knowledge and persuasion as being the first two stages towards the decision to adopt a new innovation. Within the persuasion stage, relative advantage, compatibility, complexity, trial-ability and observability were highlighted as perceived characteristics of innovation. When applied to the innovation-decision process in a sport context, these factors may need to be addressed to persuade coaches to adopt new technologies. For example, an explanation of the potential advantages of the wearable IMUs, coupled with a trial of the technology may have resulted in a high acceptance of use during competition. Giblin, Tor & Parrington (2016) outlined a number of trade-offs between the adoption of consumer-grade or "gold standard" sport technologies that included cost, expertise required to use the technology, and ease of which coaches and/or athletes can understand the data. These trade-offs also highlight key considerations which should be addressed within the persuasion stage when practitioners engage coaches regarding the adoption of new technologies.

While there was limited support from the surveyed racket sport coaches for the use of IMUs in competition, the use of IMUs in a variety of positions during training had significant positive responses. The general support for the use of IMUs during training, 96.6% of respondents, was in contrast to the limited current literature, where only 24% of respondents reported a positive experience of wearable technologies (Luczak et al., 2020). However, the response from the racket sport coaches highlighted a median value of two IMUs to be worn by the athletes during training. It is therefore important that practitioners select the placement of the IMUs carefully to ensure that the data collected is meaningful and provide insights to inform decision making.

The use of IMUs on the Non-Dominant Wrist and Dominant Wrist had significant positive responses. Wrist-worn IMUs have been found to be a reliable and valid method for stroke recognition and the assessment of movement within a controlled setting with Badminton (Shan, Sen, Fai, & Ming, 2015; Rusydi et al., 2015; Taha et al., 2016; Wang et al., 2016; Anand et al., 2017), Table Tennis (Guo et al., 2010) and Tennis (Ahmadi et al., 2009; Kos et al., 2016; Anand et al 2017; Whiteside et al., 2017). As wearable IMUs become smaller and less intrusive, and given the coaches' support for the use of IMUs in this position, it is likely that the use of IMUs on the wrist can become part of regular monitoring in racket sports.

The use of IMUs worn on the Upper Back and Lower Back in training also had significant positive responses. The use of the IMUs worn on the upper back is common across a range of sports (Chambers et al., 2015) and has been used to assess player load in racket sports (Dieu et al., 2014; Galé-Ansodi et al., 2016; Sasaki et al., 2018; Abdullahi et al., 2019; Wylde et al., 2019). However, in a study on Badminton, a low correlation was found between loading data obtained from an upper body-mounted IMU and differential ratings of perceived exertion (RPE) at the lower limbs (Wylde et al., 2019). This questions the validity of upper back worn IMUs for the measurement of playing intensity in Badminton. It has been demonstrated that upper body-mounted IMUs have limited accuracy when assessing lower limb forces and loads due to the impact forces being dissipated through the joints and body tissues between the foot and the IMU (Glassbrook et al., 2020b). A more direct measure of athlete loading may therefore be required for racket sport athletes.

The use of IMUs worn at the Lower Leg and Shoes in training had significant positive responses. Given the high prevalence of lower limb injuries in racket sports (Yung et al., 2007; Shariff et al., 2009; Goh et al., 2013), the use of lower limb-mounted IMUs may provide a more direct measure of lower limb loading in racket sport athletes. In field based sports, lower limb-mounted IMUs have been used to measure accelerations (Glassbrook et al., 2020a), impact loading and step counts (Burland et al., 2021) and to assess lower limb asymmetry (Glassbrook et al., 2020b). Given that coaches support the use of IMUs worn at the Lower Leg and Shoes in training, a similar approach warrants further investigation as a method for assessing lower limb loading in racket sports athletes.

This study sought to address a gap in the current literature as few published studies had sought to understand the perceptions of coaches towards the use of wearable technologies, such as IMUs. Despite the evidence demonstrating the reliability and validity of wearable technologies, the lack of acceptance from coaches may negatively affect the use of these technologies and the adherence of athletes. It is therefore suggested the practitioners put emphasis on understanding the perceptions of coaches towards the use of wearable technologies, as has been attempted in this study, and seek to address concerns that coaches have in order to enhance the desired symbiotic relationship between sport scientist and coach.

Limitations

The authors acknowledge a number of limitations to the current study. The sample size used in this study was comparatively small and included a mixture of coaches from various racket sports. Further insights could potentially be gained from a larger sample of sport specific coaches. In addition, the perceptions of athletes were not included in this study, which represents an additional area for further study.

Conclusion

This study sought to assess the perception of racket sport coaches on the use of IMUs during training and competition. It was found that racket sports coaches were supportive of the use of IMUs during training. While coaches also indicated support for the use of IMUs during competition, no IMU placement was found to have a significantly positive response. This suggests that while coaches understand the benefits of collecting data from IMUs during competition, there remains concerns regarding inconvenience to the athlete, lack of comfort, and appearance.

For use in training, IMUs positioned at the Upper Back, Lower Back, Dominant Wrist, Non-Dominant Wrist, Non-Dominant Lower Arm, Dominant Upper Arm, Lower Leg and Shoe had significant positive responses. Wrist-worn IMUs have been used for shot detection and movement assessment, and have the potential to be used as a regular monitoring tool during training. While upper and lower back-mounted IMUs are commonplace across a range of sports, the distance between the IMU and the foot-ground contact means that the position may not be suitable for assessment of lower limb loading. As the use of IMUs positioned at the Lower Leg and Shoe had positive responses from racket coaches, the use of lower limb-mounted IMUs for load monitoring in racket sports warrants further investigation.

References

Abdullahi, Y., Coetzee, B., & van den Berg, L. (2019). Relationships Between Results of an Internal and External Match Load Determining Method in Male, Singles Badminton Players. *Journal of strength and conditioning research*, 33(4), 1111–1118. https://doi.org/10.1519/JSC.0000000000002115

Ahmadi, A., Rowlands, D., & James, D. A. (2009). Towards a wearable device for skill assessment and skill acquisition of a tennis player during the first serve. *Sports Technology*, 2(3-4), 129-136. https://doi.org/10.1002/jst.112

Anand, A., Sharma, M., Srivastava, R., Kaligounder, L., & Prakash, D. (2017). Wearable Motion Sensor Based Analysis of Swing Sports. *16th IEEE International Conference on Machine Learning and Applications (ICMLA)*, (pp. 261-267). https://doi.org/10.1109/ICMLA.2017.0-149

Anik, M. A., Hassan, M., Mahmud, H., & Hasan, M. K. (2016). Activity recognition of a badminton game through accelerometer and gyroscope. *19th International Conference on Computer and Information Technology (ICCIT)*, (pp. 213-217). https://doi.org/10.1109/ICCITECHN.2016.7860197

Baca, A., Dabnichki, P., Heller, M., & Kornfeind, P. (2009). Ubiquitous computing in sports: A review and analysis. *Journal of Sports Sciences*, 27(12), 1335-1346. https://doi.org/10.1080/02640410903277427

Bampouras, M. T., Cronin, C., & Miller, K. P. (2012). Performance analytic processes in elite sport practice: An exploratory investigation of the perspectives of a sport scientist, coach and athlete. *International journal of performance analysis in sport*, 12(2), 468-483. https://doi.org/10.1080/24748668.2012.11868611

Bańkosz, Z., & Winiarski, S. (2020). Using wearable inertial sensors to estimate kinematic parameters and variability in the table tennis topspin forehand stroke. *Applied Bionics and Biomechanics*. https://doi.org/10.1155/2020/8413948

Barris, S., & Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Medicine*, 38(12), 1025-1043. https://doi.org/10.2165/00007256-200838120-00006

Blank, P., Hoßbach, J., Schuldhaus, D., & Eskofier, B. M. (2015). Sensor-based stroke detection and stroke type classification in table tennis. *Proceedings of the 2015 ACM International Symposium on Wearable Computers*, (pp. 93-100). https://doi.org/10.1145/2802083.2802087

Boyd, L. J., Ball, K., & Aughey, R. J. (2011). The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. *International journal of sports physiology and performance*, 6(3), 311-321. https://doi.org/10.1123/ijspp.6.3.311

Boyer, E., Bevilacqua, F., Phal, F., & Hanneton, S. (2013). Low-cost motion sensing of table tennis players for real time feedback. *International Journal of Table Tennis Sciences*, 8, 1-4. https://hal.archives-ouvertes.fr/hal-01106920

Burland, J. P., Outerleys, J. B., Lattermann, C., & Davis, I. S. (2021). Reliability of wearable sensors to assess impact metrics during sport-specific tasks. *Journal of sports sciences*, 39(4), 406-411. https://doi.org/10.1080/02640414.2020.1823131

Chambers, R., Gabbett, T. J., Cole, M. H., & Beard, A. (2015). The use of wearable microsensors to quantify sport-specific movements. *Sports medicine*, 45(7), 1065-1081. https://doi.org/10.1007/s40279-015-0332-9

Connaghan, D., Kelly, P., O'Connor, N. E., Gaffney, M., Walsh, M., & O'Mathuna, C. (2011). Multi-sensor classification of tennis strokes. *SENSORS, 2011 IEEE*, (pp. 1437-1440). https://doi.org/10.1109/ICSENS.2011.6127084

Dellaserra, C. L., Gao, Y., & Ransdell, L. (2014). Use of integrated technology in team sports: a review of opportunities, challenges, and future directions for athletes. *Journal of strength and conditioning research*, 28(2), 556–573. https://doi.org/10.1519/JSC.0b013e3182a952fb

Dieu, O., Blondeau, T., Vanhelst, J., Fardy, P. S., Bui-Xuân, G., & Mikulovic, J. (2014). Relationship between tactics and energy expenditure according to level of experience in badminton. *Perceptual and motor skills*, 119(2), 455-467. https://doi.org/10.2466/29.PMS.119c21z3

Dobson, B. P., & Keogh, J. W. (2007). Methodological issues for the application of time-motion analysis research. *Strength and Conditioning Journal*, 29(2), 48. https://www.proquest.com/openview/5f26bd396bfb7e619757f92b5bb55e37/1?pq-origsite=gscholar&cbl=44253

Duffield, R., Reid, M., Baker, J., & Spratford, W. (2010). Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *Journal of science and medicine in sport*, 13(5), 523 525. https://doi.org/10.1016/j.jsams.2009.07.003

Edwards, S., White, S., Humphreys, S., Robergs, R., & O'Dwyer, N. (2019). Caution using data from triaxial accelerometers housed in player tracking units during running. *Journal of sports sciences*, 37(7), 810-818. https://doi.org/10.1080/02640414.2018.1527675

Fox, J. L., Stanton, R., Sargent, C., Wintour, S. A., & Scanlan, A. T. (2018). The Association Between Training Load and Performance in Team Sports: A Systematic Review. *Sports medicine (Auckland, N.Z.)*, 48(12), 2743-2774. https://doi.org/10.1007/s40279-018-0982-5

Galé-Ansodi, C., Castellano, J., & Usabiaga, O. (2016). Effects of different surfaces in time-motion characteristics in youth elite tennis players. *International Journal of Performance Analysis in Sport*, 16(3), 860-870. https://doi.org/10.1080/24748668.2016.11868934

Giblin, G., Tor, E., & Parrington, L. (2016). The impact of technology on elite sports performance. *Sensoria: A Journal of Mind, Brain & Culture*, 12(2). https://doi.org/10.7790/sa.v12i2.436

Glassbrook, D. J., Fuller, J. T., Alderson, J. A., & Doyle, T. (2020b). Measurement of lower-limb asymmetry in professional rugby league: a technical note describing the use of inertial measurement units. *PeerJ*, 8, e9366. https://doi.org/10.7717/peerj.9366

Glassbrook, D. J., Fuller, J. T., Alderson, J. A., & Doyle, T. (2020a). Foot accelerations are larger than tibia accelerations during sprinting when measured with inertial measurement units. *Journal of sports sciences*, 38(3), 248-255. https://doi.org/10.1080/02640414.2019.1692997

Goh, S. L., Mokhtar, A. H., & Mohamad Ali, M. R. (2013). Badminton injuries in youth competitive players. *The Journal of Sports Medicine and Physical Fitness*, 53(1), 65-70. https://www.researchgate.net/publication/235885246_Badminton_injuries_in_youth_competitive_players

Guo, Y. W., Liu, G. Z., Huang, B. Y., Zhao, G. R., Mei, Z. Y., & Wang, L. (2010, November). A pilot study on quantitative analysis for table tennis block using a 3d accelerometer. *Proceedings of the 10th IEEE International Conference on Information Technology and Applications in Biomedicine*, (pp. 1-4). https://doi.org/10.1109/ITAB.2010.5687806

Hughes, M. D., & Bartlett, R. M. (2002). The use of performance indicators in performance analysis. *Journal of sports sciences*, 20(10), 739-754. https://doi.org/10.1080/026404102320675602

Jacob, A., Zakaria, W. N. W., & Tomari, M. R. B. M. (2016, September). Implementation of IMU sensor for elbow movement measurement of badminton players. *2nd IEEE International Symposium on Robotics and Manufacturing Automation (ROMA)*, (pp. 1-6). https://doi.org/10.1109/ROMA.2016.7847813

Jaswal, R. S. (2020). *High-performance coaches' attitudes and beliefs regarding technology adoption* (Unpublished master's thesis). Calgary, AB: University of Calgary. http://hdl.handle.net/1880/111541

Kiang, C. T., Yoong, C. K., & Spowage, A. C. (2009). Local sensor system for badminton smash analysis. *IEEE Instrumentation and Measurement Technology Conference*, (pp. 883-888). https://doi.org/10.1109/IMTC.2009.5168575

Koon, K. T., Wangdo, K., Tan, J., & Fuss, F. K. (2005, January). Using dual Euler angles for the analysis of arm movement during the badminton smash. *Sports Engineering*, 8, 171-178. https://doi.org/10.1007/BF02844017

Kos, M., Ženko, J., Vlaj, D., & Kramberger, I. (2016). Tennis stroke detection and classification using miniature wearable IMU device. *International Conference on Systems, Signals and Image Processing (IWSSIP)*, (pp. 1-4). https://doi.org/10.1109/IWSSIP.2016.7502764

Luczak, T., Burch, R., Lewis, E., Chander, H., & Ball, J. (2020). State-of-the-art review of athletic wearable technology: What 113 strength and conditioning coaches and athletic trainers from the USA said about technology in sports. *International Journal of Sports Science & Coaching*, 15(1), 26-40. https://doi.org/10.1177/1747954119885244

Mawson, R., Creech, M. J., Peterson, D. C., Farrokhyar, F., & Ayeni, O. R. (2018). Lower limb injury prevention programs in youth soccer: a survey of coach knowledge, usage, and barriers. *Journal of experimental orthopaedics*, 5(1), 1-7. https://doi.org/10.1186/s40634-018-0160-6

Picerno, P., Camomilla, V., & Capranica, L. (2011). Countermovement jump performance assessment using a wearable 3D inertial measurement unit. *Journal of sports sciences*, 29(2), 139-146. https://doi.org/10.1080/02640414.2010.523089

Raina, A., Lakshmi, T. G., & Murthy, S. (2017). CoMBaT: Wearable technology based training system for novice badminton players. *IEEE 17th International Conference on Advanced Learning Technologies (ICALT)*, (pp. 153-157). https://doi.org/10.1109/ICALT.2017.96

Rogers, E. M. (2003). Diffusion of innovations (Fifth ed.). New York: Free Press.

Rusydi, M. I., Sasaki, M., Sucipto, M. H., & Zaini, N. W. (2015). Local Euler Angle Pattern Recognition for Smash and Backhand in Badminton Based on Arm Position. *Procedia Manufacturing*, 3, 898-903. https://doi.org/10.1016/j.promfg.2015.07.125

Sasaki, S., Nagano, Y., & Ichikawa, H. (2018). Loading differences in single-leg landing in the forehand- and backhand-side courts after an overhead stroke in badminton: A novel tri-axial accelerometer research. *Journal of sports sciences*, 36(24), 2794-2801. https://doi.org/10.1080/02640414.2018.1474535

Senington, B., Lee, R. Y., & Williams, J. M. (2020). Biomechanical risk factors of lower back pain in cricket fast bowlers using inertial measurement units: a prospective and retrospective investigation. *BMJ Open Sport & Exercise Medicine*, 6(1), e000818. https://doi.org/10.1136/bmjsem-2020-000818

Shan, C. Z., Ming, E. S. L., Rahman, H. A., & Fai, Y. C. (2015). Investigation of upper limb movement during badminton smash. *10th Asian Control Conference (ASCC)*, (pp. 1-6). IEEE. https://doi.org/10.1109/ASCC.2015.7244605

Shan, C. Z., Sen, S. L., Fai, Y. C., & Ming, E. S. L. (2015). Investigation of sensor-based quantitative model for badminton skill analysis and assessment. *Jurnal Teknologi*, 72(2). https://doi.org/10.11113/jt.v72.3891

Shariff, A. H., George, J., & Ramlan, A. A. (2009). Musculoskeletal injuries among Malaysian badminton players. *Singapore medical journal*, 50(11), 1095-1097. https://pubmed.ncbi.nlm.nih.gov/19960167/

Taha, Z., Hassan, M., Yap, H., & Yeo, W. (2016). Preliminary Investigation of an Innovative Digital Motion Analysis Device for Badminton Athlete Performance Evaluation. *Procedia Engineering*, 147. https://doi.org/10.1016/j.proeng.2016.06.341

Wang, Z., Guo, M., & Zhao, C. (2016). Badminton Stroke Recognition Based on Body Sensor Networks. *IEEE Transactions on Human-Machine Systems*, 46(5), 769-775. https://doi.org/10.1109/THMS.2016.2571265

Whiteside, D., Cant, O., Connolly, M., & Reid, M. (2017). Monitoring Hitting Load in Tennis Using Inertial Sensors and Machine Learning. *International journal of sports physiology and performance*, 12(9), 1212-1217. https://doi.org/10.1123/ijspp.2016-0683

Wright, C., Atkins, S., & Jones, B. (2012). An analysis of elite coaches' engagement with performance analysis services (match, notational analysis and technique analysis). *International Journal of Performance Analysis in Sport*, 12(2), 436-451. https://doi.org/10.1080/24748668.2012.11868609

Wylde, M., Kumar, B., Yong, L. C., & Callaway, A. J. (2019). Axis Specific Player Load to Quantify Lower Limb Biomechanical Loading in Adolescent Badminton Players. *International Journal of Racket Sports Science*, 1(1), 37-44. https://doi.org/10.30827/Digibug.57329

Yu, J., & Zhao, G. (n.d.). Study on Badminton smash for training based on sensor. *Lecture Notes in Electrical Engineering*, 224, 377-384. https://doi.org/10.1007/978-3-642-35567-7-46

Yung, P. S., Chan, R. H., Wong, F. C., Cheuk, P. W., & Fong, D. T. (2007). Epidemiology of injuries in Hong Kong elite badminton athletes. *Research in sports medicine (Print)*, 15(2), 133–146. https://doi.org/10.1080/15438620701405263

Zok, M. (2014). Inertial sensors are changing the games. *International Symposium on Inertial Sensors and Systems (ISISS)*, (pp. 1-3). https://doi.org/10.1109/ISISS.2014.6782518

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