Original article
DOI: 10.30827/Digibug.70282

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.

Matthew James Wylde [1,2]*; Nur Adilah Masismadi[1,3]; Low Chee Yong[1]; Andrew James Callaway[2]; Jonathan Mark Williams[2]

1 National Youth Sports Institute, Singapore.
2 Bournemouth University, Department of Rehabilitation and Sport Sciences, Bournemouth, United Kingdom.
3 La Trobe University, College of Science, Health and Engineering, Melbourne, Australia.

Received: 16-03-2021

Accepted: 26-08-2021

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

Correspondence author: Matthew James Wylde, matthew_wylde@nysi.org.sg

Cite this article as:
Wylde, M. J., Masismadi, N. A., Chee Yong, L., Callaway, A. J., & Williams, J. M. (2021). Placement of inertial measurement units in Racket Sports: Perceptions of coaches for IMU use during training and competition. *International Journal of Racket Sports Science*, 3(1), 45-55.

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*

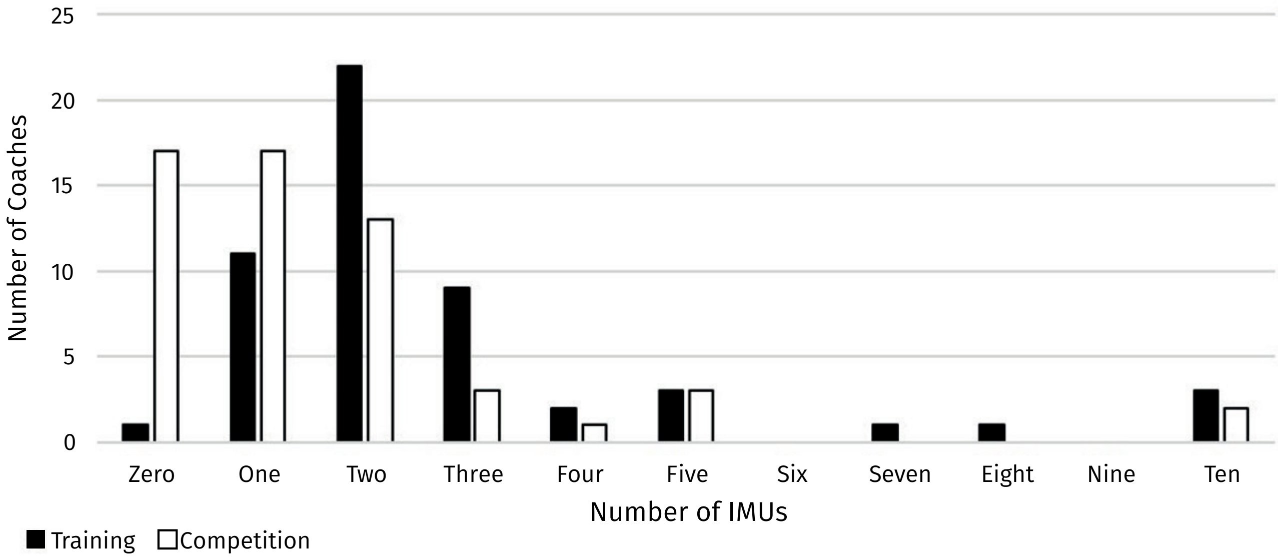

Figure 1. Maximum Number of IMUs Supported for Use During Training and Competition (Excluding Outliers Above 10 Units).

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