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The design and evaluation of an integrated training load and injury/illness surveillance system in competitive swimming

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ABSTRACT

Objective: To design and evaluate an integrated training load monitoring and injury/illness surveillance system in a competitive swimming environment.
Design: Descriptive/mixed methods.
Setting: Swim Ireland National Training Centres.
Participants: Fourteen competitive athletes and seven coaches/medical data collectors participated in the evaluation process.
Outcome measures: System satisfaction, usefulness and burden were evaluated. Barriers to the implementation and effectiveness of the system were explored.
Results: Most athletes were 'extremely' or 'very' satisfied with the overall data collection process and also found it to be 'extremely' or 'very' useful in the training centre environment. All practitioners were 'extremely satisfied with the system and found it to be either 'extremely' or 'very' useful in their role. *Process constraints* and *data access and control* were significant themes related to the athletes, while practitioners highlighted *communication and cooperation amongst stakeholders, layering context to the data, maintaining data integrity* and the *coach's influence in the monitoring process* as being important to the monitoring/surveillance process.
Conclusions: Training load monitoring and injury/illness surveillance are necessary to elevate the standard of prospective injury/illness prevention research. Integrated systems should be designed in line with key consensus statements, while also being implemented in a way that counteracts the challenges within the real-world training environment.

1. Introduction

A competitive swimming season is a year-round process where training stimuli and recovery are carefully intertwined to allow the athlete to push limits of performance whilst avoiding overtraining, injury or detraining (Hellard et al., 2019). Swimming typically involves an excess of 1000 h of training per year, incorporating 400–800 sessions (Tønnessen et al., 2014), culminating in peak performance opportunities (Hellard et al., 2019). These significant demands lead to a higher incidence of injury during training than in competition (Soligard et al., 2017) and may result in swimmers training and competing with persistent health problems (Prien et al., 2017).

Injury prevention in sport requires collaboration (Impellizzeri et al., 2020) and a robust framework to act within (Finch, 2006). The Translating Research into Injury Prevention Practice (TRIPP) framework outlines the necessity of high-quality surveillance data combined with a clear understanding of the aetiology and risk

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factors of injury (Finch, 2006). Studies have found associations between muscular length (Harrington et al., 2014), core endurance (Tate et al., 2012) and shoulder pain in division one female swimmers, while training load has also been found as a contributing factor in national-level swimmers (Ristolainen et al., 2014). World Aquatics, formally known as Fédération Internationale de Natation (FINA) has published several studies exploring in-competition injuries and illnesses with many of these studies recommending out of competition prospective injury and illness surveillance (Engebretsen et al., 2013; Mountjoy et al., 2010, 2015, 2016; Prien et al., 2017; Soligard et al., 2017). Two studies have examined injury surveillance in national level (Matsuura et al., 2020) and collegiate swimmers (Boltz et al., 2021). Both studies, while robust in design, provide recommendations which include more detailed athlete exposure data (i.e., type or intensity of training, distance swam, and cardiovascular/exertional indices) in parallel with their injury surveillance procedures (Boltz et al., 2021; Matsuura et al., 2020). Monitoring risk factors such as training load, in parallel with the surveillance data, can give insights into the aetiology of injuries and support the translation of the information into actionable interventions.

Training load can be defined as the cumulative amount of stress placed on the athlete (Griffin et al., 2020) and can be divided into internal and external loads (Drew & Finch, 2016). External loads quantify work while internal loads describe the response to that work (Drew & Finch, 2016). In swimming, distance, time or speed are habitually used to monitor the external training load, with heart rate or session rate of perceived exertion (sRPE) typically used to monitor internal training load (Barry et al., 2022a; García-Ramos et al., 2015). Additionally, subjective athlete markers of well-being are commonly tracked in swimming (Barry et al., 2022a) as a method of monitoring psychosocial stress in the athlete (Griffin et al., 2020; Saw et al., 2017; Sinnott-O'Connor et al., 2018). Monitoring objective and subjective metrics of this nature is essential to effective programme design (Impellizzeri et al., 2020) and viewed as an influencing factor in the incidence of injury (Gabbett, 2020). Monitoring systems should be feasible and scientifically grounded (Griffin et al., 2020). Barriers such as stakeholder engagement, resource constraints and system functionality need to be considered (Barry et al., 2022a) while overcoming limited time, funding, compliance and poor staff communication are necessary for effective implementation (Barry et al., 2022b; Yeomans et al., 2019). The World Health Organisation (WHO) injury surveillance guidelines also recommend that an end-user evaluation process should be conducted after at least six months of the system being operational (Holder & World Health Organization (WHO), 2004). The goal of the evaluation process is to assess the data collection process and end-user satisfaction, usefulness and burden. This will aid in the identification of system flaws and opportunities for development and maintain system relevance within a dynamic environment (Holder & World Health Organization (WHO), 2004).

Quality injury/illness surveillance is a crucial aspect of injury/illness prevention, whilst the monitoring of potential risk factors in parallel to the injury/illness surveillance period is also of critical importance. Despite much research investigating the relationship between injury/illness and training load, a causative relationship has yet to be identified (Barry et al., 2021). Thus far, this lack of clarity may be down to methodological constraints in both the means of implementing the integrated system or expressing the injury/illness incidence relative to accurate training load measures (Barry et al., 2021; Boltz et al., 2021; Matsuura et al., 2020; Trinidad et al., 2021). Therefore, the primary aim of this study was to describe the design and implementation of an integrated system running concurrently throughout a competitive swim season. The secondary aim was to conduct an end-user evaluation of the integrated system and to make future recommendations regarding such systems.

2. Methods

2.1. Experimental approach to the problem

The nature of the problem centred on the ability to design and implement an integrated training load and injury/illness surveillance system to be used within competitive swimming. The experimental approach aligned with procedures by Griffin et al. (Griffin et al., 2020). Step one consisted of exploring current training load and injury surveillance practices which have previously been established (Barry et al., 2022a; 2022b). Step two was to design and implement an integrated system. Step three was participant recruitment and familiarisation. Step four was implementing data collection, analysis and auditing practices. Step five was the end-user evaluation of the integrated system after one year of data collection.

2.2. Design and implementation

The integrated system was built on the findings of stage one. It also engaged with the World Aquatics and/or International Olympic Committee (IOC) consensus statements (Bahr et al., 2020; Mountjoy et al., 2016) and guidance from Soligard et al. (Soligard et al., 2016) and Schwellnus et al. (Schwellnus et al., 2016). The integrated system was designed with two elements of data collection: 1) athlete self-reported data and 2) practitioner-reported data. Athlete self-reported data were collected through the online application Kitman Labs™ (*kitmanlabs.com*), which could be accessed through mobile phones. The practitioner data were inputted into a bespoke Microsoft Excel worksheet, designed in line with the Orchard Sports Injury and Illness Classification System (OSIICS) (Orchard et al., 2020).

2.3. Athlete self-reported data

Athlete self-reported data were divided into two categories: 1) well-being data; and 2) training load data. All streams of data collected are outlined in Fig. 1. Subjective measures of well-being have been shown to respond acutely and chronically to training load and are recommended for inclusion alongside other objective monitoring practices (Saw et al., 2017). In this case, sRPE −TL and session volume in meters were monitored. Athletes rated their perceived exertion on the modified Borg scale (1-10) (as adapted from the Borg CR10 scale (Borg, 1998)) after each session. They were also asked to record the session volume in meters and minutes where applicable and select the activity type (e.g. swimming, S&C − strength, racing, S&C − conditioning). sRPE −TL was calculated by multiplying the sRPE by the duration of the activity, as outlined previously (Foster et al., 2001; Griffin et al., 2020; Wallace et al., 2008).

2.4. Practitioner reported data

A nominated physiotherapist was assigned to each training venue as the medical data collector (MDC). Data consisted of any injury or illness sustained and were defined as per Bahr et al. (Bahr et al., 2020). Injury and illness were subcategorised as medical attention or non-medical attention and time-loss or non-time loss. Time-loss and medical attention are defined as per Mountjoy et al. (Mountjoy et al., 2016). Injury/illness mode of onset was classified on a continuum consistent with Bahr et al. (Bahr et al., 2020). Circumstances of injury were divided into training or competition

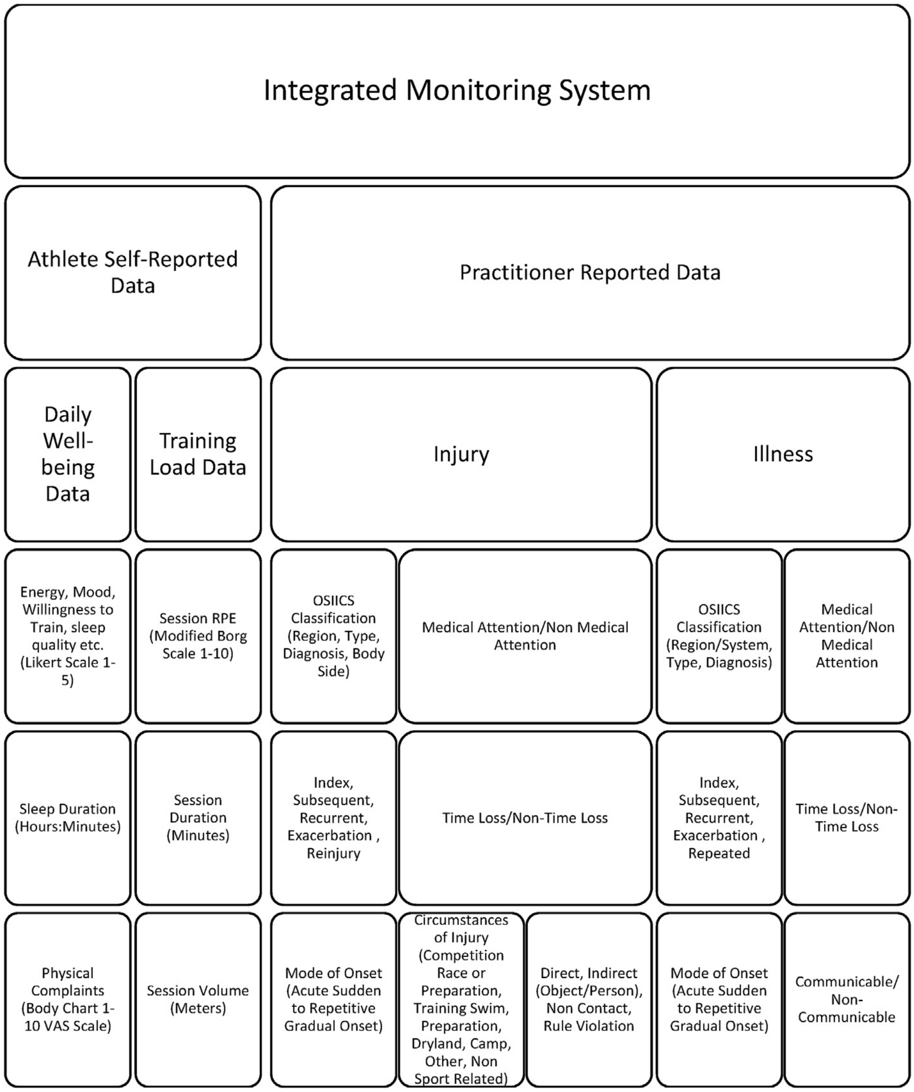

Fig. 1. Structure of the integrated monitoring system employed.

(Mountjoy et al., 2016) with a further classification as to the level of contact (direct, indirect, non-contact) (Bahr et al., 2020). Illnesses were sub-categorised as communicable or non-communicable (Mountjoy et al., 2016). Subsequent, recurrent or exacerbation of injuries/illnesses were classified as described in Bahr et al. (Bahr et al., 2020). The severity of the injury/illness was recorded as the duration of time loss as directed by Bahr et al. (Bahr et al., 2020). Time loss was reported from the date of onset until the athlete was fully available for training and competition. Fully available was clarified as without modification of training prescription, modification of technique or deficits in performance directly related to the injury or illness. The OSIICS was employed to determine the location, type and diagnosis of injury/illness.

2.5. Participants

Two of Swim Ireland's (the national governing body for swimming on the island of Ireland) National Training Centres were involved in the data collection; National Centre Dublin (NCD) and National Centre Limerick (NCL). A total of 24 athletes trained within Swim Ireland's National Centre programmes during the data collection period. These athletes are classified as World Class ($n = 1$), Elite/International Level ($n = 11$) and Highly Trained/National Level ($n = 12$) (McKay et al., 2022). These National Centres were identified to implement the integrated system and all 24 athletes were recruited. Athletes' education (handbook) and familiarisation began 12 weeks before the start of the formal data collection period. The MDC in each centre was provided with an education session and reference handbook on the procedures and definitions to be employed during the data collection period. Ethical approval was granted by the University's Ethics Committee (2019_10_09_EHS).

2.6. Auditing practices

Auditing procedures included sending daily text reminders to athletes to input their data. Athlete data were manually cross-checked weekly to verify the presence or absence of data. Absent or suspicious data (excessively high/low) were highlighted, investigated and rectified where needed. A biweekly group email was sent out to the MDCs to confirm the continuity and completeness of ongoing or resolved cases.

2.7. Evaluation

In line with the WHO's injury surveillance guidelines (Holder & World Health Organization (WHO), 2004), an end-user evaluation process should be conducted to identify flaws and opportunities for improvement. After the first season of implementation, an end-user evaluation was carried out, as illustrated in Fig. 2. Survey reporting was conducted in line with the (S1) CHERRIES checklist (Eysenbach, 2004), while interviews and focus groups followed the (S2) COREQ checklist (Tong et al., 2007). The surveys (administered via Qualtrics) were designed to evaluate aspects of the integrated system that athletes (N = 24), coaches (N = 4) and MDCs (N = 3) were directly involved with, on a daily basis. Athletes and coaches evaluated the self-reported data collection process from their unique perspectives, while the MDCs evaluated the practitioner-reported data collection processes. Athlete surveys were circulated at the end of the domestic competitive season and before the Tokyo Olympic/Paralympic Games. The survey was circulated through email to all participating athletes and remained open for a two-week period. MDC/coaches surveys were followed up with semi-structured online focus group sessions (MDCs) or semi-structured interviews (coaches). Additional reporting details of the survey, interview and focus group design, circulation and analysis can be found in S3.

3. Results

3.1. Athlete self-reported data

In total, 14/24 athletes responded to the survey. The response rate was potentially affected by the close proximity to the end of the domestic competitive season. The majority of athletes were transitioning to their off-season, selected athletes were travelling to Tokyo in preparation for the Olympics/Paralympics and 5 athletes had ceased training within the National Centres by the time the survey was circulated. The sample consisted of 10 males and 4 females, which is a representation of the athlete gender balance of the centralised swimming athlete population in Ireland. The majority of athletes noted that they were ‘extremely’ or ‘very’ satisfied (n = 11) with the overall data collection process. Athletes reported that the monitoring process was ‘extremely’ or ‘very’ useful (n = 12) or ‘moderately useful’ (n = 2) to the training centre. Furthermore, they found the monitoring process was ‘extremely’ or ‘very’ useful (n = 8) or ‘moderately’ or ‘slightly’ useful (n = 6) to themselves as athletes. All athletes noted that inputting well-being data were ‘extremely’ or ‘very’ easy, with the majority echoing the same sentiment for sleep hours (n = 13), physical complaint (n = 11) and training load data (n = 12). The remainder of responders noted that inputting sleep hours, physical complaint and training load data was ‘moderately’ or ‘slightly’ easy. Athletes were also asked how burdensome the process of inputting training load data were during competition periods, in comparison to the daily training environment. The majority of athletes agreed (n = 11) that there was no difference between the two environments. However, the remaining responders noted that inputting training load in the daily training environment was ‘moderately’ burdensome in comparison with ‘moderately’, ‘very’ or ‘extremely’ burdensome in the competition environment. Athletes highlighted the measures they felt best represented their ability to train as planned were energy (n = 8), followed by physical complaint (n = 2), muscle soreness, sleep quality, swim volume and willingness to train (all n = 1).

A thematic analysis was conducted on the open questions, with the higher-order themes of ‘data access/control’ and ‘process constraints’ featuring consistently amongst the responses.

Athletes noted that “*we can't see if we've filled something already*” (R1) or “*recalling if I have filled out every piece of detail as required*” (R5) were barriers related to their access and control of the system. Athletes highlighted solutions by noting, “*If you could see what forms you've filled out … ….. If you made a mistake, you could delete the volume or a session yourself …*” (R1). The athlete's ability to see and track their recorded information, be able to modify it and take ownership of its consistency and accuracy would be of great benefit to the overall system.

The logistics of the monitoring process also increased the burden on the athlete. Athletes noted several instances where the usability of the system was seen as a barrier; for example, “*the number of different places to go in the app to fill out the data can be tedious.*” (R5) or “*typing in data, clicking buttons works well but putting numbers in can be slow*”(R13). Athletes also suggested that the student-athlete and early morning culture of the sport heightened the burden, “*the only issue is you have to do it in the early mornings when I'm half asleep*” (R3) and “*especially during college weeks, it can be hard to stay on top of data*” (R7). Finally, athletes proposed solutions to these issues through small adjustments to the reporting process. For example, “*I would like the volume and RPE to be on the same page instead of having to go to different places within the app*” (R4) or “*Have a box for sleep hours during the day for nap times*” (R8).

3.2. Practitioner reported data

Head coaches noted that their primary roles in the monitoring process ranged from decision making on the data provided, making data inferences, and information dissemination. Assistant coaches also noted decision making in relation to the data provided was a primary aspect of their role, but included liaising with athletes for inputting data, analysing data or data cleaning. All coaches rated how satisfied they were with the integrated system with both head coaches noting ‘extreme satisfaction’ and assistant coaches being either ‘somewhat’ or ‘moderately’ satisfied. All coaches rated the system as being ‘extremely useful’ or ‘very useful’ to them in their role and noted that analysing athlete's data was either ‘slightly’ or ‘not at all’ burdensome. Coaches highlighted the measures they felt best represented the athletes' ability to train as planned were sleep quality (n = 2) and sleep duration (n = 2).

MDCs unanimously stated the system was either ‘extremely’ or ‘somewhat’ good in terms of their overall satisfaction with the system. They also agreed that the system was gathering sufficient injury/illness surveillance information and was a ‘very accurate’ representation of the actual injury and illness profile sustained over

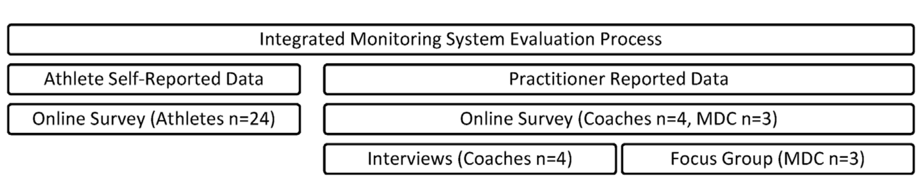

Fig. 2. Outline of the evaluation process.

the season. The MDCs noted that the system was either ‘extremely’ or ‘somewhat’ good in terms of ease of use, time taken to record data, visual appeal and suitability of the data fields.

3.3. Focus group and interviews

Four themes were identified from the analysis of the interviews with coaches and the focus group with the MDCs.

1) Communication and co-operation amongst stakeholders.
2) Layering context to the data.
3) Maintaining data integrity.
4) The coach's influence in the monitoring process.

3.4. Communication and cooperation amongst stakeholders

This theme outlines key situations where the integrated system was a fundamental driver of multidirectional communication between the athlete, support staff and coaches. Firstly, participants described how the system provides a medium for the athlete to communicate indirectly with the coaching staff, particularly where they might find face-to-face communication difficult.

“it creates that conversation rather than them having to come to us going. “Hey look, I've got a problem”. I think they find that quite difficult to communicate”(R6)

Meanwhile, it also improved the coaches’ ability to have targeted conversation with the athletes about their wellbeing:

“I'm looking at .....if anyone got a niggle, has everybody slept well? …and all they do is allow, when we come out the office to say, Morning! Everything OK? Oh yeah, just slept terrible but I’m fine” (R4)

The system also provides opportunities for the coach to have more informed conversations with the wider multidisciplinary team, allowing them to highlight specific areas of concern and seek appropriate interventions:

“… communication across the staff in terms of how we as staff interact and then we can use that information to say, right? Well, there's obviously an issue here. Do we need to modify things …” (R5)

3.5. Layering context to the data

Many participants felt that while the primary action of collecting the raw information is useful, adding a layer of context to the data is necessary for optimum understanding and decision making. One such layer of context was ensuring the accuracy and integrity of the raw data before taking action:

“(the system) gives you snippets of information, but it doesn't then lead to a knee jerk decision. It leads to a conversation, is everything okay?… actually, I just pressed the wrong button” (R4)

Participants also noted that they would cross-check their understanding of the data with the athlete to ensure their corresponding reaction is appropriate:

“if we have had reduced sleep or quality of sleep and we might be able to modify (the session), but we only really do that once I spoke to (the athlete) to see really how they were feeling”(R5)

A key layer of information is the athletes' chronic reporting patterns. Participants noted that the athlete's reporting history is taken into consideration before taking action:

“ …. .if it's consistently bad or consistently good, at least it's consistent and we then start to get a gauge of where (the athlete) score themselves”(R4) or “(This athlete) always reports his mood as one so it doesn't really matter”(R4)

3.6. Maintaining data integrity

Data compliance and accuracy lead to data integrity and should take priority within the process. Maintaining data accuracy requires strict adherence to the consensus guidelines; however, maintaining data compliance requires a more flexible approach in the practical environment. Participants highlighted that getting a full, but not perfect, picture was deemed sufficient in their environment when it came to data compliance.

“You’re inevitably never going to have everyone do it perfect all the time, so nearly perfect most of the time is quite good”(R7)

A lack of staff time and resources were two barriers to good data accuracy and compliance that were highlighted during the evaluation process.

“It's just a time to go check it up and make sure that it's all there ….”(R7)

“How resourced medicine is across the board in all the high-performance sports in Ireland. It's so poor”(R2)

Athlete status or performance level (tier) was seen to impact data compliance. How established the athlete is within the training environment may lead to flexible levels of accountability in using the system consistently. Coaches noted that younger athletes who are not fully compliant, receive education on monitoring practices and benefits to change their reporting habits.

“if they are teens or youth athletes … …I think that's absolutely a question around why they need to value this, and an explanation of how you need to value it because this is what we do for you” (R4)

However, established athletes may require a more individualised approach which can affect data compliance.

“ …. .if I was to have a conversation with them regularly about (maintaining data collection) ….I would then lose the opportunity to maybe get another meaningful message across to them …..I just decide the data is just irrelevant …”(R4)

Athlete status within the high-performance system can have a significant impact on the threshold of medical attention, thus affecting data accuracy.

“… some athletes get different treatment and preferential treatment than others and that's just a nuance of high-performance sport”(R2)

One responder summarised: *"high-performance sport is elite and it isn't equitable"(R2)*.

Finally, individual beliefs and attitudes also impacted how MDCs respond to athletes and therefore can have an effect on injury/illness surveillance accuracy.

> *"some athletes … ….are used to getting stuff escalated and then others are not ….it's not necessarily related to the presentation that's in front of you …"(R2)*

> *" …. one person who might have a little sore shoulder who swims through it …..somebody else who's like, I can't swim ….and you know it's the exact same presentation"(R1)*

3.7. The coach's influence on the monitoring process

Coaches' level of engagement with the system and its outputs can have a significant impact. Participants noted that coaches who are more data driven tend to interact with the system in a greater way.

> *"I think if you're not quite as data driven, you wouldn't see the benefit of it. I know there's some coaches that struggle to read it, but they're also the ones that are not data driven"(R4)*

A clear aspect of this theme was that coaches interacted with aspects of the system they found to be useful irrespective of scientific rigour surrounding the measure.

> *"I'm not massive on RPEs, I'm not massively driven by how someone scores it and then it related to a training week and load"(R4)*

All coaches highlighted that sleep (quality or quantity) was a key metric that they tracked closely in the athletes; however, they framed its importance as performance consistency and enhancement.

> *"certain athletes not getting enough sleep … that then means that their ability to recover from one session to the next is going to be hampered. So the quality of the next session is going to be impacted in a negative sense"(R5)*

4. Discussion

The primary aim of this study was to describe the design and implementation of an integrated system running concurrently throughout a competitive swim season. The secondary aim was to evaluate the integrated system after a full season of data collection and to make future recommendations regarding such systems. The design and evaluation of such a system can guide the competitive swimming community in training load and injury/illness surveillance best practice. The TRIPP model highlights that only research that is adopted by applied practitioners will be successful in preventing injuries (Finch, 2006). Accordingly, the design of this integrated system had to not only comply with best practice but also be adopted effectively in a real-world setting. In compliance with stage one of the TRIPP framework, the system was designed prospectively, across two separate training venues and in conjunction with injury/illness surveillance consensus guidelines (Bahr et al., 2020; Mountjoy et al., 2016) and training load monitoring best practice (Bourdon et al., 2017; Schwellnus et al., 2016; Soligard et al., 2016). The adherence to key consensus guidelines maintains methodological consistency, allows accurate comparison of studies (Bahr et al., 2020) and replication in a practical setting. Additionally, the integrated system sought to comply with stage two of the TRIPP model. This stage corresponds with the need to provide an aetiological understanding of the injury/illness surveillance data. In the absence of stage two, epidemiological researchers and practitioners are left with exemplar injury/illness (frequency/pattern) data (*What Is Epidemiology?, 2016*) but no understanding of the determining causes or risk factors (Finch, 2006).

The optimal implementation of a monitoring system is underpinned by its simplicity and acceptability (Holder & World Health Organization (WHO), 2004). Subsequently, the system needs to minimise burden and place the user at the centre of the design, evaluation and improvements. This system was evaluated with these principles in mind. High levels of satisfaction in the overall system design from both the athletes and coaches/MDCs were found. Additionally, the system's usefulness and ease of use were rated positively with a low perception of burden within the monitoring process. Despite these positive findings, during the end-user evaluation, it was found that athletes highlighted some constraints within the monitoring process. Athletes noted that exam periods (where student-athlete workload increases) and early mornings were the most onerous or challenging periods. This is a key finding as academic stress has been related to the incidence of injury (Hausken-Sutter et al., 2021) thus elevating the need for monitoring during such a high-risk period.

Barriers to the implementation of monitoring systems have been well documented in recent years with stakeholder compliance and engagement being significant determinants for success (Griffin et al., 2020; Yeomans et al., 2019). Athlete evaluation of the system showed that data access and control is a key aspect of maintaining data compliance. Athletes noted that having access to their inputted data, with the ability to review, edit or delete data in real-time would improve data compliance and accuracy. Interestingly, the coaches/MDCs also highlighted data compliance and accuracy as a significant aspect of the monitoring process. Coaches/MDCs commented that a *"nearly perfect"* dataset was sufficient, as compliance across the whole group longitudinally was unrealistic. Diminished compliance is a common theme regarding monitoring in the research (Neupert et al., 2019), and while there are strategies to improve compliance through education, there is also a practical solution to addressing the *"inevitable"* occurrence of missing data (Griffin et al., 2021). Griffin et al. (Griffin et al., 2021) outlined a method to address missing data. However, this method needs to be investigated further within an individual sport environment. Practically, it is useful to have both interventions working in conjunction throughout the season. Long-term education of the athlete is necessary for improved compliance. However, in the short term, the ability to address missing data effectively is also pertinent for practitioners.

Coaches/MDCs also highlighted that data compliance is related to athlete status. In the practical environment, non-compliant younger athletes may receive an educational intervention into the benefits of the system. However, more established athletes may receive more flexibility within the process. Athletes within this study received education through an athlete handbook and a 12 week familiarisation process. These findings show that more continuous athlete education and feedback throughout the season may be necessary to maintain higher levels of engagement and compliance. Support staff who take an individualised approach to athlete compliance should consider the cost/benefits of this strategy. Duignan et al. (Duignan et al., 2019) found athlete-specific education was a key aspect of improving engagement but also noted that inequity between adhering and non-adhering athletes diminished motivation and created interpersonal distrust and disharmony (Duignan et al., 2019). An inequitable athlete environment was also highlighted within our findings where athlete status (tier level, funding, etc.) would have an impact on the level of medical attention received. Athletes in the upper tiers of the system would typically get access to medical attention at an earlier stage or a lower symptom threshold than an athlete of a lower tier. This, despite adherence to research-based consensus guidelines, could create hidden nuances when reporting medical attention data. Given this individual variation, grouping data by tier level may be the most valid (or accurate) representation of the data.

Stakeholder communication is one of the most commonly cited uses of a monitoring system (Saw et al., 2015). In this instance, coaches/MDCs highlighted that the system provided a communication platform for athletes to identify any issues which they might not otherwise verbally communicate. This placed the responsibility on the coaches/MDCs to initiate a conversation with the athlete regarding their wellbeing disclosures. It also fostered a more targeted approach by the coaches/MDCs within the multidisciplinary team (MDT) by allowing them to attend to specific athletes with concerns in a more directed manner. This potentially reduces the time between wellbeing disclosure and intervention which is ideal in a performance environment. This communication pathway also allows for a layer of context to be generated. Coaches/MDCs noted that in many cases the acute response was not a *'knee jerk'* decision and action should not be taken until after a conversation has taken place. The context of knowing the athlete and their chronic reporting trends is also a key aspect of the information. Before acting, a coach can mediate their response based on their prior knowledge of the athlete's reporting history or personality traits. This response was echoed by Saw et al. (Saw et al., 2015) where they described interpreting the athlete's data based on knowing the athlete's circumstances and personality traits as being the 'art' of coaching. Keeping this in mind, coaches/MDCs should be aware that when implementing a monitoring system, there should be an inbuilt lead time where data is collected consistently, observed for trends and understood in relation to the individual athlete before being used as a decision-making tool.

Previous research has shown that coaches not engaging with or acting upon athlete data was a significant barrier within the monitoring process (Griffin et al., 2020). In this instance, coaches highlighted many ways in which they engaged with the system; however, it was clear that a coach's personal opinions of certain metrics dictated the degree of engagement. It was noted that coaching style may be an influencing factor with one coach stating those who are less data-driven will not see the benefits in the system. It was also mentioned the use of RPE was not a priority based on the coach's own opinions of the metrics and not based on a scientific argument (validity, reliability, etc.) A key mismatch between the athletes' and coaches' perception of what key metrics they felt best represented their ability to train as planned also exists. Coaches very specifically value the sleep duration and quality metrics, while athletes largely prioritised the energy rating. This conflict of beliefs could lead to a degree of athlete mismanagement where coaches may not react as readily to a poor energy rating versus a poor sleep rating based on personal bias. A multidirectional feedback loop, where coaches and athletes engage in open conversation about the expectations and beliefs on the monitoring process should occur regularly to reduce this disparity.

Finally, the collection of accurate illness information was seen as a challenge. The qualitative findings highlighted that potentially the under-resourcing of medical support meant that in the practical environment MDCs were not receiving adequate information to create an accurate diagnosis record. In the absence of a sports medicine doctor attached to a training centre, athletes went to their home General Practitioner for medical attention resulting in the subsequent diagnosis being relayed back to the MDCs by the athlete. Similarly, for an illness which did not require medical attention but was affecting the athlete (*"stuff above the throat … head cold, or maybe some mild GI symptoms"),* MDCs often relied on a coach to relay a diagnosis which was not deemed to be an appropriate reporting pathway. These barriers to reporting illness information may lead to an under-reporting of medical attention illnesses and an inaccurate reporting of non-time loss, non-medical attention illnesses in particular. Going forward, a system of this nature should be tailored to suit the available resources. In the absence of adequate medical support, symptom based reporting by the individual athlete may be the preferred reporting avenue. Despite the inherent bias, athlete self-reported measures can broaden the scope of injury/illness surveillance and can be implemented in conjunction with a valid and reliable questionnaire (e.g. Health Problems Questionnaire) (Clarsen et al., 2014; Toohey & Drew, 2020).

5. Limitations

A key strength of this study is also a weakness. Research into elite sports continuously face discord between the inherent small population to draw from and the unique viewpoint that the population can offer. To this end, limiting the research design to solely include two of Swim Ireland's National Training Centres resulted in a small participant sample size. Future research may overcome this by adjusting the study design to increase the number of data points (continuous evaluation over the season rather than cross-sectional) (Skorski & Hecksteden, 2021) or expanding the study design to cooperating elite training centres internationally (Impellizzeri, 2017).

6. Conclusions

The integration of training load monitoring and injury/illness surveillance is necessary to elevate the standard of prospective injury/illness surveillance research in competitive swimming. The design of the integrated system provided for research-based data collection processes, which received positive appraisal. However, the design must be complemented by an effective implementation process to achieve robust and accurate data collection. A continuous end-user evaluation process is a necessary step which allows for the evolution of the system to meet the dynamic demands of a sporting environment. One key finding of the evaluation process highlighted that the resources available should align with the needs of the integrated system, allowing for improved collection of all data. Findings also highlighted that the implementation should occur gradually allowing for a period of uninterrupted data collection where staff can gain a deeper understanding of individual athlete reporting habits. Once accomplished, coaches should use the system as an "alert" to potential issues, allowing the coach to instigate communication with the athlete. Considering all information, including the athletes reporting history and personality traits before taking decisive action is recommended. Furthermore, the continuous collection of accurate and consistent data should be prioritised particularly during periods of high external demands (e.g. exam periods). Athletes should receive additional attention to maintain compliance or coaches should employ different monitoring strategies during these periods (e.g. increased verbal communication/objective markers). Athlete education into the benefits and uses of the monitoring process is necessary to maintain high levels of athlete compliance, however this education needs to occur early in the monitoring process and be continuous throughout the season. Similarly, coaches need to be educated on the cost/benefits of treating higher tiered athletes differently within the monitoring process than their lower tiered counterparts.

Despite creating a flexible and individualised approach for certain athletes, there is a high risk of developing an adverse athlete culture leading to larger and subsequent challenges. Future design and implementation of integrated systems needs to adhere to best practice through consensus guidelines, while also working to counteract these real-world challenges.

Ethics approval

Ethical approval was granted by the University's Ethics Committee (2019_10_09_EHS) and participants gave informed consent to their information being used for research and publication purposes.

Ethics approval

Ethical approval was granted by the University's Ethics Committee (2019_10_09_EHS).

Consent for publication

Approved.

Code availability

Not applicable.

Availability of data and material

Data and materials are available from the corresponding author, upon reasonable and appropriate request.

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Authors' contributions

All authors contributed to the review conception and design. Material preparation, data collection and analysis were performed by LB, TC, ML, KMcC and CP. The first draft of the manuscript was written by LB and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declaration of competing interest

Authors declare that they have no competing interests. LB is an employee of Swim Ireland, but this does not constitute a competing interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2023.01.007.

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