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# Mental skills training in elite sports environments: Current status of integration

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ABSTRACT

*The role of mental skills training (MST) in elite sports is continually growing in prominence as several studies have emphasized its value to athletes and coaches for several years. Fewer studies have investigated how MST might successfully be integrated into elite sports franchises, clubs, and teams. This study examined the current status of MST integration in these environments. It also explored the obstacles to successful integration and how these might be overcome. A qualitative approach and phenomenological design were employed to collect data via emailed open-ended questions and follow-up semi-structured in-depth interviews and the data was analysed through thematic analysis (TA). Thirty-five leaders working in elite sports participated. Findings revealed that while all participants (n = 35) endorsed the importance of MST in elite sports, 11% (n = 4) had incorporated it effectively into their environments. Unsuitable practitioners, a lack of leadership support, and insufficient time for successful application were highlighted as significant obstacles hindering successful integration. Recommendations to overcome these obstacles included the prioritisation of MST by leaders of elite sports environments, formulating bespoke MST strategies for their teams, clubs, or franchises, recruiting suitably qualified MST providers, and providing them with sufficient time and resources to effectively implement these strategies.*

## 1. Introduction

Athletes need physical and mental skills to succeed at the highest levels of their sport, especially during pinnacle events (Cottrell, 2018). Sports teams, franchises and clubs have recognized this for an extended period. For example, numerous franchises that participate in the Super Rugby tournament have incorporated mental skills training (MST) since the inception of the competition in the 1990s. This also holds true for other sports such as major League Baseball (Nightengale, 2018).

Research on the mental side of performance in sport has also expanded as athletes and teams continuously seek a competitive advantage. Numerous studies have shown how training athletes from various sporting codes in mindfulness, cognitive and behavioral mental skills contributed towards improving their overall performances (Brown & Fletcher, 2017, Bühlmayer et al., 2017, Gross et al., 2018, Gould & Maynard, 2009, Hardy et al., 2017, Harita et al., 2022, Hut et al., 2021, Noetel et al., 2019, Sparks & Ring, 2022, Vidic, 2021, Vidic & Cherup, 2022). Other studies have also found that athletes who engaged in MST participated in their sports for longer periods and at higher levels (Clowes & Knowles, 2013, Cotterril, 2011, Czech et al., 2004, Hayes, 2019, Hazell et al., 2014, Hogue, 2019, Mccann et al., 2001, McGowan et al., 2015). These athletes also tended to generally display more confidence, less pre-performance anxiety (Ong & Griva, 2017) and more emotional stability away from their sport (Hill et al. 2014, Ong & Griva, 2017, Patrick & Hrycaiko, 1998). Research has also revealed that most athletes are receptive to undergoing MST as part of their athletic development (Wrisberg et al., 2009). These apparent benefits along with the openness by athletes to engage in this form of training appear to

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highlight why it has seen a growing application in most sporting codes. However, some studies have also found that despite many coaches valuing MST, few of them made a deliberate attempt to develop these skills among their athletes (Creasy et al., 2009).

Zakrajsek et al. (2018) shed some light on why this might be the case by interviewing nine certified athletic trainers (ATs) from a National Collegiate Athletic Association Division 1 institution to investigate their perceptions and experiences of sport psychology services for student-athletes. Among their findings it was revealed that despite the participants being aware of these services in their environments, there still existed some confusion and uncertainty among them around what these services entailed and when, where how they could be accessed. To obtain clarity of the extent to which MST was being integrated among elite sports teams, clubs and franchises, it led the researchers to question whether mental skills were truly valued by their leaders and, to what extent they were being integrated into their overall performance strategies? Also, the researchers questioned what obstacles were potentially hindering such integration and how could they be overcome?

## 2. Methods

To answer the aforementioned questions, the study adopted a qualitative approach and phenomenological design. This was deemed the most suitable approach as the phenomenological design aims to explore the subjective experiences and views of a particular phenomenon from a group of people (Creswell, 2014). When considering the limited knowledge that could be identified pertaining to MST integration into elite sports environments, this approach was deemed applicable given that it was both explorative and descriptive in nature. Furthermore, phenomenological research provides a thorough understanding of participants' lived experiences which was also sought from the participants in this study (Creswell, 2014).

In the context of this study, a team, club, or franchise was deemed elite if it competed at the highest level of the sport. This included e.g., participating in top tier domestic competitions, transnational or international tournaments and events. It was also regarded as elite if its athletes and coaches participated on a full-time basis and were contracted and financially remunerated for their participation. Furthermore, an MST provider included both registered sports psychologists and mental skills coaches who were not necessarily registered and qualified psychologists. Therefore, all consultants who provided MST for elite sports teams, clubs, and franchises were viewed as MST providers for the purpose of this study. Finally, the following definition by Cumming (2018, para. 1) was adopted as the working definition of MST for its comprehensiveness and simplicity: "Also known as psychological skills training, MST involves the systematic development and application of mental techniques and skills to enhance mental qualities that promote performance and well-being".

### *2.1. Participants*

The first author invited potential participants (n = 50) to participate. Inclusion criteria stipulated that participants needed to occupy a leadership position such as a head coach, assistant coach or performance director at an elite team, club, or franchise in order to ensure that their responses were relevant to the research questions. It was also a requirement for these teams to have already engaged with MST in their environments as this was the focus of the study. They also needed to be able to converse in English, as this was the language used to gather the data.

Among the respondents who agreed to participate (n = 35), some were appointed as head or assistant coaches (n = 5) while others were performance directors (n = 30). They also identified as male (n = 32) and female (n = 3) with a mean age of 44 years. They represented different sporting codes, namely Major League Baseball, rugby union, rugby league, cricket, and field hockey. They averaged 8.3 years of leadership experience at elite teams, clubs, and franchises and represented various regions so as to obtain a broad perspective instead of solely focusing on a single sporting code within in one country. These included Australia & New Zealand (n = 13), Europe & the United Kingdom (n = 11), and North America (n = 11). No additional information about them could be included in an attempt to protect their confidentiality as most of them were well-known to the public.

The participants formed a non-random convenience sample given that they were selected by the first author to request their participation. Convenience sampling is frequently used in qualitative research as it allows participants to be included because they are the easiest for the researcher to access (White & McBurney, 2012). This was also the case in this project because, as an experienced mental skills coach, the first author had come to know the participants through his work with various elite sports teams, clubs, and franchises. He was therefore able to utilize his existing relational network to recruit them to participate in the study. As the focus of this study was on the state of integration of MST within elite sports teams, clubs, and franchises, they were specifically approached on the basis of being experienced coaches and performance directors operating in such environments. Although they were recruited through convenience sampling, effort was made to ensure that they represented as diverse a range of sporting codes and locations as possible, thereby ensuring that the data was collected from multiple and varied sources.

The data was originally collected by the first author for service delivery purposes between 2021 and 2022. Therefore, the participants were contacted again in 2023 to request their permission to utilize the data for research purposes as well. Ethical approval was sought and granted for this purpose from the University of Otago Ethics Committee (Reference number: D23/029).

### *2.2. Procedure*

Once all the potential participants had been identified, they were approached via email by the first author to determine their willingness to participate in the study. Only those who voluntarily agreed to participate were then emailed the questions indicated in the following section and requested to complete it within ten days. This approach was selected to make it as convenient as possible for the participants to participate given that they all had very busy schedules. They were also asked whether they would agree to a personal follow-up interview about the topic.

After ten days, those among them who agreed to participate (n = 35) had emailed their responses to the first author. Follow-up semi-structured in-depth interviews were also conducted with those who agreed to it (n = 5) by the first author. These interviews were conducted online and lasted an average of 30 minutes each.

### *2.3. Data collection*

The following questions were posted to the participants:

1. Do you believe MST plays an important role in overall performance?
2. Does your team, club, or franchise currently incorporate MST in its overall performance strategy?
3. Does your team, club, or franchise implement MST on a weekly basis?
4. What are the major obstacles that have prevented MST from being integrated into your team, club, or franchise?
5. How do you believe obstacles towards MST integration in elite sports environments could be overcome?

Additional probing questions were added where indicated or in instances when participants did not spontaneously elaborate on their answers during interviews.

### *2.4. Data quality & integrity*

Participants voluntarily partook in the study and signed an informed consent form on which confidentiality and anonymity were ensured. Given the fact that many of the participants were well-known to the public, special care was taken not to reveal their identities. Furthermore, the overall trustworthiness of the study was ensured by employing the strategies of credibility, dependability, conformability and transferability throughout the project as prescribed by Guba (1981) and synthesized by Krefting (1991) as well as following the guidelines proposed by Korstjens and Moser (2018).

### *2.5. Data analysis*

Thematic analysis (TA) was used to analyze the data and the six steps proposed by Braun and Clarke (2006) served as the primary guide for this purpose. These steps were familiarization, generating initial codes, grouping codes according to similarity, reviewing of themes, defining and naming of themes and composing the final report.

Each interview was recorded and transcribed verbatim by the first author. Following this, the first author also anonymized and reviewed each of them to ensure grammatical accuracy. Both authors completed the first three steps proposed by Braun and Clarke (2006) individually while making use of an inductive, bottom-up approach to allow the codes to interpret the data as opposed to drawing on any existing theories. This was done to minimize potential bias or influence on each another's processes of analyzing the data during these initial steps. The authors then met to discuss their analyses and completed the remaining steps together which ultimately culminated in this publication.

Triangulation was achieved throughout this process through the frequent meetings between the authors to discuss the findings. This enabled a broader perspective to be created from which to interpret the data and allow their interpretations to be debated before agreeing on the final themes & sub-themes reported in the following section (Korstjens & Moser, 2018).

## 3. Results

The first question posed to all participants was whether they regarded MST to be important for overall performance. All of them answered this as 'yes' (100%). The second question inquired whether their team, club, or franchise possessed a mental skills strategy at the time as part of their overall performance strategy. Four participants answered this questions as 'yes' (11%). The third question inquired whether MST took place on a weekly basis at their club, franchise or team. Five participants (15%) answered 'yes' to this question.

The fourth question asked the participants what they considered the major obstacles to be that prevented MST from being integrated into their environments. Their responses yielded the following themes and subthemes as depicted in Table 1:

Table 1: Obstacles hindering integration of mental skills training (MST).

| **Theme 1: Obstacles regarding MST service providers** | |
|---|---|
| Sub-theme | Difficulty identifying appropriate MST providers |
| Sub-theme | Inadequate understanding of elite sport environments by some MST service providers |
| **Theme 2: Obstacles regarding organizational cultures** | |
| Sub-theme | Lack of organizational support from key stakeholders |
| Sub-theme | Siloed organizational approaches |

In the interest of brevity, all quotations highlighting the themes and sub-themes could not be included in this article. Those included in italic below were selected on the basis of their similarity to other related comments. Reference to the number of respondents who made similar comments was however included. A comprehensive list of the data can be made available upon request.

The first theme revolved around challenges with MST providers. The first sub-theme referred to the challenge of identifying an appropriate individual to deliver such a service. Twenty-eight participants commented on this sub-theme, with one stating that "we have struggled to find someone [MST provider] who can connect with the group and deliver quality [MST] work." Another factor that frequently contributes to this sub-theme is the difficulty of measuring the actual impact of MST. Fourteen participants referred to this. One commented that "we have found it difficult at times to measure the impact of the mental skills work."

The next sub-theme pointed towards a lack of understanding of the particular environment by MST providers as perceived by key stakeholders. This also included a perceived lack of understanding of elite sport environments. Eighteen of the participants referred to this and one stated: "You [MST providers] have to be able to understand the pressures and demands [of elite sport] to be relevant to the players."

The next theme centered on challenges relating to the organization's existing culture. The first sub-theme highlighted the apparent lack of support from certain key stakeholders to include and promote MST. Sixteen participants commented on this sub-theme, one of whom highlighted the challenge of obtaining sufficient support for MST from their leaders: "The biggest challenge for us is getting the support of the GM [General Manager] and board [of Directors]. They seem to think that only weak players need help with the mind [MST] work." A related sub-theme highlighted by the participants was that MST is often implemented separately or in a siloed manner. For instance, one participant explained: "We haven't been able to integrate the [MST] work across our environment, we need to figure out how to do this [with other performance areas], or we won't get the buy-in we need."

The themes and sub-themes depicted in Table 2 emerged from participants' responses to the fifth question of how they believed obstacles towards MST integration in elite sports teams, clubs and franchises could be overcome:

Table 2: Recommendations of how obstacles hindering integration of mental skills training (MST) could be overcome.

| **Theme 1: Desirable attributes of service providers** | |
|---|---|
| Sub-theme | Effective communication skills |
| Sub-theme | Understanding of elite sport |
| **Theme 2: Enabling environmental factors** | |
| Sub-theme | Support from leaders |
| Sub-theme | Prioritization and time allocation for mental skills training |

The first theme referred to desirable skills and attributes of MST providers. The first sub-theme was that of effective communication skills to which two participants referred. One of them indicated: "We were fortunate enough to find someone [MST provider] who was able to hold the room and engage the players as well as connect with them in a one-on-one context." This also translated to how MST providers communicated their specific knowledge, which two participants referred to. One of them stated that "the best mental skills coaches [MST providers] I have worked with managed to create and communicate simple tools and practices that allowed theory to come alive."

The next sub-theme which emerged from the responses referred to the importance of MST providers requiring a thorough and clear understanding of elite sport. One participant explained: "Our [MST] provider identified early the mental demands of our game at this [elite] level and was able to tailor their program to meet those needs." Another participant stated that "there are some highly qualified people out there, but working in elite sport is very different from other jobs."

The next theme revolved around environmental factors that enabled effective integration of MST within elite sports environments. The first sub-theme highlighted here referred to the critical role of support for MST by leaders in these environments. Three participants referred to the importance of this, with one saying: "Once our leaders believed in the [MST] work, then everyone jumped on board." This is closely related to the next sub-theme of these teams, clubs and franchises prioritizing MST by allocating sufficient time for it to be implemented effectively. Three participants mentioned the importance of this with one explaining how this was done effectively in their environment:

> We [coaches and performance directors] would do a mental review and preview each week, just like the other aspects of the game. We use an expert [MST provider] to help us with this process and provide enough time for it to be important.

In summary, the results indicated that despite all the participants agreeing that MST is important for overall performance in elite sport, most of them indicated that it was not being effectively integrated into their environments. This appeared to indicate a contrast between the perceived and actual value of MST within their environments. Furthermore, many of them did not engage the services of a MST provider on a regular basis or had included MST in the overall performance strategies for their clubs, franchises, or teams. The main reasons the participants sighted for this were difficulties with finding suitable MST providers who possessed a satisfactory understanding of elite sport environments. Furthermore, organizational challenges such as a lack of support for MST by some leaders and applying it in a siloed approach were also noted. To overcome these barriers, participants suggested that MST providers need to develop effective communication skills and a sound understanding of what the needs are of athletes and coaches at the elite level of sport. Furthermore, certain factors surrounding MST needed to be developed including more support from leaders and allocation of sufficient time for it to be incorporated effectively within elite teams, clubs, or franchises.

## 4. Discussion

Results from the present study offered valuable insights into coaches and performance directors from elite sport teams, clubs, and franchises' perceptions of the integration of MST in their environments. Participants provided important insight into their perceived value of MST, the barriers hindering its optimal implementation and recommendations on how to overcome such barriers. These results are timely given the increasing interest around the globe in MST, sport psychology, mental performance, and mental health at the elite level of sport (Durand-Bush et al., 2022).

An interesting aspect that emerged from the findings of the present study was that the attributes of MST providers were highlighted in both the obstacles towards successful integration of MST as well as the recommendations of how it might be overcome. It also appeared that in instances where participants indicated successful integration had taken place, the MST providers had communicated and positioned themselves effectively within these environments. A poor understanding of the elite sport landscape by some MST providers along with a poor understanding of the unique demands that it places on athletes and coaches who operate at this level was further highlighted as a particular obstacle. Simultaneously, a clear understanding of this landscape combined with effective communication skills of MST providers were highlighted as ways to overcome this obstacle. This was closely related to the findings of a study conducted by Chandler et al. (2014) that had investigated the personal qualities of effective sport psychologists from the perspectives of sports physicians who closely worked with them. It found the personal qualities of empathy and trustworthiness to be particularly important to being an effective sport psychologist. It also highlighted the importance of approachability, agreeability, and possessing the general ability to get along with people to build effective relationships with coaches and athletes alike. The study also found that effective sport psychologists could portray professionalism in practice by simultaneously portraying both humility and self-confidence. Furthermore, they possessed a clear understanding of their roles within the environment in which they operated and worked solely within the boundaries of what they were qualified for. Finally, the study highlighted the importance of the sport psychologist as a person requiring a strong drive towards empowering and genuinely caring for those they worked with in combination with an ability to communicate effectively (Chandler et al., 2014).

Apart from the individual attributes, skills or abilities of MST practitioners, the results further highlighted that the prevailing culture at elite sports clubs, franchises and teams played an important role in either hindering or enhancing the effective integration of MST. In this regard, leaders such as coaches and performance directors seemed to play a particularly important role. This is as leaders have been identified in the literature to set the tone in the creation and maintenance of prevailing organisational cultures (Shein & Schein, 2016). Zakrasjek et al. (2014) also found in their research that it was critical to obtain the ‘buy in’ from at least one leader for MST to be successfully integrated in an organisation. This appeared similar to the findings of this study as participants also remarked that in instances where leaders where they operated had ‘bought in’ to MST, it culminated in more support and time for it to be implemented and integrated into these environments. However, it was further reported by the participants that the opposite also held true where leaders had not ‘bought in’ to MST at their clubs, franchises, or teams.

Given the aforementioned, the results from this study pointed towards a situation where a combination of factors appeared to hinder or promote the effective integration of MST into elite sporting environments. In some cases, effective integration appears to be taking place where the organisational culture and its leaders are receptive to MST in combination with a suitably qualified MST practitioner who possesses a clear understanding of the environment and optimal communication skills. In instances where this is not the case, there appears to be a lack of integration of MST. To promote effective integration of MST at elite sports teams, organisations and franchises, the authors proposed the following recommendations based on the responses from the participants.

## 5. Recommendations

The results of this study provided valuable insights from the perspectives of coaches and performance directors with extensive experience at the elite level of sport. These insights translated into the following practical recommendations for leaders of elite sports teams, clubs, and franchises as well as MST providers who aim to work in these environments. The following recommendations are for leaders:

### *5.1. Incorporate MST providers into management teams*

A team can have an MST provider appointed on its payroll who is tasked with facilitating the MST, but that is very different from having this individual truly integrated into the environment as one participant explained:

> I wonder if we set up the Psych's [or MST providers] for failure by not having a system in place to help them integrate. We look to the [MST] provider if things go wrong, but I wonder if we need to look at ourselves first.

It is therefore recommended that MST providers be fully incorporated such as by including them in important team management meetings as early as possible following their appointment and allowing them to provide input on decisions. As experts in mental skills, they are often in a unique position to provide valuable insights that might otherwise be overlooked.

### *5.2. Include an MST strategy in the overall performance strategy*

If a team, club or franchise already had an MST strategy in place, it would most likely provide a clear picture of what is required from MST in that context. Leaders can then focus on recruiting a provider who is best suited to implement it. As such, it is recommended that finding an appropriate a provider take place after a clear MST strategy was first established and included in the overall performance strategy.

### *5.3. Ensure the MST provider possesses an understanding of elite sport*

The preferred MST provider should ideally be able to provide a clear track record to illustrate their understanding of the unique contextual demands of elite sport in addition to their qualifications. Possessing certain qualifications such academic qualifications does not necessarily automatically equate to a sufficient understanding and knowledge of this environment and the pressures it places on coaches and athletes who operate within it.

### *5.5. Allocate sufficient time for MST*

Another recommendation is to allocate sufficient time in training programs for the implementation of MST. If the work is truly regarded as valuable and relevant by key stakeholders to overall performance, there needs to be sufficient time allocated for its optimal implementation to occur. How much time is, however, difficult to determine given that each elite team, club, or franchise is unique. Time is generally also a very precious commodity in these environments. As such, to determine how much time would be sufficient will depend on the unique needs of the coaches and athletes. If they feel they are obtaining sufficient benefit from the amount of time allocated to MST, it most likely is sufficient and no changes would be required. However, one of the participants made the following statement regarding insufficient time allocated to MST: “Our [elite sports] environments are quite time poor, so the mind work [referring to MST] tends to happen behind the scenes and, to be honest, is a bit of an afterthought.”

If the views among players and coaches are like the view expressed by this participant, it might warrant more time to be allocated towards MST. A brief survey among players and coaches might give an answer to this. The participants expressed that keeping MST behind the scenes and having someone available for it rather than intentionally integrating time for MST in their training programs could silo MST and hinder its integration. The challenge would be to carve out time to invest in this work in already busy schedules. Effective integration will, however, only occur if MST is truly regarded as a key component of overall performance and time then dedicated for players and coaches alike to grow collectively from accessing it. The next recommendations are for MST providers.

### *5.5. Ensure support from key stakeholders before accepting a new role*

Optimal integration of MST within an elite sports team, club, or franchise dependents on support from all the critical stakeholders, including athletes, coaches, support staff and performance directors to drive the work throughout their environment. The findings revealed that the work would not flourish if it was conducted in a siloed manner. Historically, MST has often been viewed as a luxury, additional service, or something athletes would engage in when recovering from injury or when noticing a dip in performance (Zakrajsek et al., 2018). In recent times, there however appears to have been a gradual move away from this perception, for instance with increasing numbers of elite athletes speaking more openly about their mental health. Despite this, a stigma associated with working with the minds of athletes still persists in some sectors (Moreland et al., 2018). For this to be overcome and optimal integration of MST to occur, it is recommended that evidence for the contribution towards overall performance of MST be presented by MST providers to all stakeholders in elite sports environments to inform them of its importance and value. An opportunity to do so should ideally be discussed and confirmed with leaders in these environments prior to accepting a role of MST provider while discussions around mutual expectations and contracting are still in progress.

### *5.6. Measure and communicate the impact of MST*

When referring to the measurement and impact of MST, one participant stated:

> In other areas of performance we give a clear mandate of what we want to happen in the program, there are regular checkpoints to ensure we are on track, and we review the work after the season, with the mental stuff [MST] we tend to find a person and just let them loose, we don't follow best practice.

Another participant echoed this statement in saying that "we have found it difficult at times to measure the impact of the mental skills work [MST]." These comments highlighted the importance of measuring and providing feedback by MST providers to all key stakeholders on the impact of MST. When however considering the nature of MST, this can be challenging. For instance, concrete datasets such as those produced from GPS trackers used in other performance areas cannot be produced in the same way for MST. As such, other performance areas that produces such tangible outcome datasets may be viewed by some stakeholders as more credible. This is logical given that it could be easier to determine if a training program was producing the desired outcomes if its progress was measured against such concrete data. This could also lead to situations whereby coaches and athletes may dedicate more time, resources and energy towards these performance areas given that their outcomes appear more tangible. This in turn might contribute to slower or ineffective integration of MST in elite teams, clubs, and franchises.

The more subjective nature of MST requires a different approach to measure it's impact, and research is continuously providing more and improved options to do so. For instance, numerous evidence-based psychometric instruments are already available to MST providers, like the Athletics Coping Skills Inventory 28 (Smith et al., 1995), Psychological State Test for Athletes (Díaz-Tendero et al., 2020), Sports Personality Questionnaire (Raharjo, 2018), Psychological Skill Inventory (Milavic et al., 2019) and Ottawa Mental Skills Assessment Tool-3 (Durand-Bush et al., 2001), to name but a few. The selection of which of these instruments to use should ideally flow from a thorough analysis by MST providers of the unique needs of the elite teams, clubs, or franchises in which they operate. More recently, Durand-Bush et al. (2022) developed a comprehensive, evidence-informed framework that might also better assist MST providers as part of this process, namely the Gold Medal Profile for Sport Psychology (GMP-SP). This framework was established to guide MST providers and sports organisations with their design, delivery, tracking, and evaluation of MST. Regardless of which tools or approaches MST providers opt to use, it is recommended that they measure and provide feedback on the impact of the MST they provide to all key stakeholders at various intervals throughout their involvement to promote more effective integration of MST at elite clubs, teams, and franchises.

## 6. Limitations

Thirty-five participants took part in this study which represented a relatively small sample size. Due to this they could not represent all sporting codes (e.g., football, basketball, golf, and motor sports were not represented). They also held existing relationships with the first author which might have influenced their responses and only three of them identified as female. Therefore, care should be taken not to generalise the findings of the present study to all elite sports environments. In hindsight, the authors also felt there was latitude to have potentially included additional questions that might have provided more additional valuable data. Despite this, the study managed to achieve its aim of providing valuable insight on the current status of MST integration into elite sports environments from a variety of leaders with extensive experience in these contexts. For future studies it would be beneficial to expand on these findings by potentially conducting quantitative or mixed methods studies with larger sample sizes, including more female participants and more sporting codes. As athletes were not included among the respondents in this study, future studies could also include them to obtain their perspectives on the topic. Furthermore, all the participants from this study operated in countries and organisations that predominantly represented what could be described as Western cultures. It would, therefore, be beneficial for future studies to also include participants from other cultures. This would hopefully also highlight their unique perspectives and needs when it comes to MST in their environments.

## 7. Conclusion

Studies on the benefits of MST in sport were identified from the literature, however, few could be identified that had examined its state of integration within elite sports teams, clubs, and franchises. This study aimed to take a step towards filling this gap by obtaining an indication on the current status of MST integration within these environments. Thirty-five participants took part in the study and provided their valuable insights as experienced leaders who understood both the context and demands of elite sports environments. Despite being from different regions and involved in different sporting codes, similar ideas and challenges frequently appeared to emerge from their responses. These revealed that despite being valued, several obstacles still persisted in their environments that inhibited MST from being optimally integrated. Some recommendations were included based on these findings to potentially overcome these obstacles. Additional research is required with larger samples and different respondents on how best to overcome these obstacles and integrate MST more effectively into these environments in the future.

## Conflict of Interest

The authors declare no conflict of interests.

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# The association between motivation and physical activity among forensic and rehabilitation inpatients in Aotearoa New Zealand

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ABSTRACT

*The aim of this study was to examine the association between motivation and physical activity among forensic and rehabilitation inpatients living with serious mental illness in Aotearoa New Zealand (NZ). Patients from a long-stay forensic and rehabilitation inpatient facility were recruited to participate in an interview that collected information on their personal characteristics (e.g., age, gender), motivation to be active using the Behavioural Regulation in Exercise (BREQ-3-PA), and physical activity levels using the Simple Physical Activity Questionnaire (SIMPAQ). The association between motivation and physical activity was examined using Spearman's rho and classified according to accepted thresholds for correlation coefficient effect sizes. All participants ($n = 24$) met global and national physical activity recommendations. All correlations between the different physical activity types and the relative autonomy index score were negligible (Spearman's rho < 0.3), as were correlations between total moderate-vigorous physical activity and each of the six motivation subscales (Spearman's rho < 0.3). Participation in exercise and sport was positively correlated with intrinsic motivation (Spearman's rho = 0.356) and identified regulation (Spearman's rho = 0.391). All other correlations between physical activity types and the motivation subscales were negligible (Spearman's rho < 0.3). In summary, there was limited evidence of an association between physical activity participation and motivation to be physically active. Results may have been affected by the effects of institutionalisation within this population, whose ability to act autonomously is severely limited. Further research is required to better understand the potential benefit of motivational interventions to encourage physical activity participation, and what form they should take.*

## 1. Introduction

The physical health of people living with mental illnesses has been noted as a priority area for clinical practice and research internationally (Firth et al., 2019) and in New Zealand (Te Pou, 2020). A considerable mortality gap exists between those with and without severe mental illness (SMIs; e.g., schizophrenia, bipolar disorder, and major depressive disorder) (Thornicroft, 2011). This persistent inequity is largely attributable to the relatively poor physical health of individuals with SMI, among whom non-communicable diseases are responsible for more premature mortality than suicide (Correll et al., 2017; Hayes et al., 2015; Olfson et al., 2015; Swaraj et al., 2019; Vancampfort et al., 2017). Review level evidence indicates that these long-term health inequities mirror lower levels of physical activity participation by people experiencing SMI and that encouraging participation in

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physical activity can be an effective intervention for improving physical health in this population group (Bull et al., 2020; Schuch et al., 2017; Stubbs et al., 2016; Vancampfort et al., 2017). Specifically, effective promotion of physical activity can contribute to improving both the physical and mental health of people experiencing SMIs.

The socio-ecological model has been widely used to understand physical activity behaviour and develop interventions to improve participation (Bauman et al., 2012; Sallis & Saelens, 2000). Within populations under mental health services, physical activity is influenced by public policy (funding, restrictions imposed under the Mental Health Act such as e.g., leave status), community (facility policy, facility design and accessibility), interpersonal (peer networks, support from mental health professionals), and individual factors (e.g., self-efficacy, attitudes, motivation) and personal characteristics (e.g., gender, ethnicity, socio-economic status, health status, disability). While each of these factors are important antecedents of physical activity behaviour, an individual's motivation has been shown to be a significant predictor of physical activity for people living with SMI (Vancampfort et al., 2017). Among the most popular conceptualisations of human motivation – supported by a large body of evidence – is self-determination theory (SDT) (Deci & Ryan, 2000).

Broadly, SDT posits that there are two types of motivation: autonomous and controlled. Autonomous motivation comes from within an individual, and is comprised of three types. Intrinsic motivation describes undertaking an activity out of enjoyment or mastery (e.g., playing a favourite sport); identified regulation describes undertaking an activity because it is aligned with one's personal values (e.g., exercising because it improves physical health); integrated regulation describes undertaking an activity because it is linked to one's identity (e.g., being a 'runner' or a 'cyclist'). Conversely, controlled motivation is externally driven. External regulation is prototypical of this – being active on the basis of receiving a reward or avoiding a punishment. More relevant to physical activity is introjected regulation – which describes ego-based motivation such as exercising to attain a certain body ideal, often as a result of societal pressure. Individuals often experience several such types of motivation at any one time, and they can fluctuate over time (Lindwall et al., 2017). In the presence of autonomous motivation for physical activity, long-term adherence and psychological well-being are more likely if the surrounding social and physical environment are conducive to participation (Jenkins et al., 2021; Teixeira et al., 2020).

SDT also posits that key to autonomous motivation is the satisfaction of three basic psychological needs within a given behavioural context: competence, autonomy, and relatedness (Deci & Ryan, 2000). In the context of physical activity, autonomy refers to an individual feeling that they have choice in their physical activity (Ryan & Deci, 2000), competence refers to feeling able to meet specific activity-based goals (e.g., a certain amount of steps), and relatedness refers to feeling socially connected to others within the context of physical activity (e.g., peers or instructors; Edmunds et al., 2006). As a result of having these three psychological needs met within a given context, autonomous motivation is more likely. There is existing evidence regarding the importance of satisfying psychological needs in the development of motivation for physical activity (Teixeira et al., 2020).

While research into the relationship between motivational type and physical activity among individuals with SMI is limited, existing research does indicate an association between autonomous motivation for physical activity and physical activity behaviour (Sørensen, 2006; Vancampfort et al., 2015). However, despite these findings, very few studies have involved people who are institutionalised in mental health care facilities, which is a unique and important context that warrants further investigation. Our prior exploratory research in this population suggested motivation to be a key factor, with sedentary participants spontaneously raising 'low motivation' as a barrier to being physically active (Every-Palmer et al., 2018).

Therefore, the aim of this study was to assess the association between motivation and physical activity among a population of forensic and rehabilitation inpatients experiencing SMI in NZ. This will provide insight into the relative importance of motivation as a determinant of physical activity behaviour in this population group. In doing so, our objective is to understand how to improve support for sustained participation in physical activities that are beneficial to the physical and mental wellbeing of SMI inpatients at mental health care facilities.

## 2. Methods

### 2.1. Participants

Participants were recruited from long-stay forensic and rehabilitation inpatient units (Te Korowai Whariki) at Ratonga Rua o Porirua Hospital, which houses patients with various mental illnesses (psychosis, bipolar, schizoaffective disorder) and serves five district health boards across the lower North Island of Aotearoa New Zealand. Patients have different access to leave according to their legal status and the specific ward in which they reside (of which there were four), with these wards ranging from medium security (restricted access) to open access.

Inclusion criteria stated that participants must: be a current inpatient of the forensic and rehabilitation mental health services; have a diagnosis of a psychotic disorder and/or a mood disorder with psychotic features (ICD-10 or DSM-5 criteria); meet diagnostic criteria for a serious mental illness (clinician-administered); have the capacity to provide informed consent (as assessed by the treating psychiatrist); and have spent a minimum of two months in the service (such that treating teams could have adequate time to treat their mental state and to ascertain that they have capacity to give informed consent). Exclusion criteria included: a mental state considered by the treating psychiatrist as too unstable to participate in the trial; and an inability to speak English.

Patients were invited to study information sessions organised by hospital staff (i.e., not members of the research team, thus minimising coercion). Patients who indicated interest were provided with an information sheet that included research team contact details. Once contact was made and the patient agreed to participate, informed consent was obtained. Data collection took place from June 2021 to September 2021. Participants' access to physical activity opportunities varied according to the ward on which they resided, but all included a minimum of weekly access to a personal trainer and access to cardio fitness equipment and weight areas. In addition, swimming pool access (subject to approval by an on-site occupational therapist) and a weekly sports group were available to participants. Opportunities for walking included one on-site treadmill and pathways around the facility grounds. For those with approved leave into the community, there was also the opportunity to walk to the nearest town with amenities (shops, takeaways) located approximately one kilometre away.

Ethical approval was granted by the University of Otago Ethics Committee (New Zealand). Māori consultation was undertaken with the Ngāi Tahu Māori Consultation Committee. Participants' time was acknowledged with a NZ$40 supermarket voucher.

### *2.2. Procedure*

Physical activity and motivation data were collected at one time point for each participant, via face-to-face interviews that lasted approximately 20 – 30 minutes. Study data were collected and managed using REDCap electronic data capture tools hosted at the University of Otago. All participants identifying information (names and other identifiable information) was removed and linked by a secure keycode. Only the principal investigator and the researcher administering the data collection tools had access to the raw data.

### *2.3. Measures*

#### *2.3.1. Participant characteristics*

Key descriptive data collected included: age, gender, ethnicity, and smoking status. One participant did not report their smoking status. Other variables recorded included: leave status (whether the participant was able to leave their unit and if so the number of hours/week approved leave); access to physical activity support; primary psychiatric diagnosis; other psychiatric diagnoses; current psychotropic medication; patient status (forensic or rehabilitation); whether the participant was under the Mental Health Act; non-psychiatric diagnoses and associated medication; and height and weight which were used to calculate body mass index (BMI). Data were retrieved from participants' patient records, with their explicit permission (requested during the informed consent process).

#### *2.3.2. Physical activity*

The Simple Physical Activity Questionnaire (SIMPAQ; Rosenbaum et al., 2020) was designed to measure self-reported physical activity, sedentary behaviour, and sleep of people living with a serious mental illness. The SIMPAQ consists of five sections, covering sleep, sedentary behaviour, walking, physical activities such as exercise and sport, and any other incidental physical activities (e.g., gardening, household chores). The SIMPAQ was conducted via face-to-face interviews. The SIMPAQ has been shown to be valid and reliable across various samples (Rosenbaum et al., 2020). For the purposes of this study, physical activity was separated into: i) walking; ii) exercise and sport; iii) other physical activity. As per the SIMPAQ analysis rules, total moderate-vigorous physical activity was also estimated by summing the walking and the exercise and sport domains (Rosenbaum et al., 2020; Simple Physical Activity Questionnaire, 2019).

#### *2.3.3. Motivation for physical activity*

The Behavioural Regulation in Exercise (BREQ-3-PA version; Markland & Tobin, 2004; Wilson et al., 2006) consists of 24 items, each answered on a five-point Likert-type scale from zero (not true for me) to four (very true for me). There are six subscales each containing four items: i) Intrinsic motivation (e.g., 'I am physically active because I enjoy it'); ii) Integrated regulation (e.g., 'I consider physical activity as part of my identity'); iii) Identified regulation (e.g., 'It's important to me to be regularly physically active'); iv) Introjected regulation (e.g., 'I am physically active because other people say I should be'); v) External regulation (e.g., 'I take part in physical activity because my friends/family/partner say I should'); and vi) Amotivation (e.g., 'I don't see the point in being physically active'). Mean scores were calculated for each subscale. These scores were also weighted and summed according to established protocols to give a composite overall score known as the Relative Autonomy Index (RAI) (Connell & Ryan, 1985; Grolnick & Ryan, 1987; Howard et al., 2020; Markland & Ingledew, 2007).

### *2.4. Statistical approach*

All analyses were conducted using SPSS Version 26.0 (IBM, Armonk, NY). There were initially 38 participants who agreed to be part of the study and met the inclusion criteria. Three participants provided incomplete responses to SIMPAQ items and were excluded. A further 11 participants were excluded after applying the SIMPAQ cleaning rules (i.e., nine participants provided responses that accounted for less than 18 hours of their day and two participants reported walking and/or exercise values exceeding the 2.5 SD threshold) (Simple Physical Activity Questionnaire, 2019). Analyses were conducted on the remaining 24 participants. Descriptive statistics were computed to characterise the data. Spearman's rho correlation coefficients were used to examine the association between each of the motivation variables and the physical activity variables because the data was not normally distributed. We applied widely accepted effect size parameters from the field of behavioural science to define the strength of association for the calculated correlation coefficients (i.e., 0.0 – 0.3 = negligible correlation, 0.3 – 0.5 = low correlation, 0.5 – 0.7 = moderate correlation, 0.7 – 0.9 = high correlation, 0.9 – 1.0 = very high correlation) (Hinkle et al., 2003).

## **3. Results**

### *3.1. Participants characteristics*

Descriptive statistics for the participant characteristics are presented in Table 1. The mean age of participants was 34.3 ± 12.5 years. Most participants were men (75.0%), Māori (58.3%), had leave from their unit (75.0%), used more than 10 hours of leave/week (58.3%), did not smoke (56.5%), and were classified as having obesity (70.8%). The mean BMI was 36.3 ± 7.8 kg/m$^2$.

All participants were receiving compulsory treatment under mental health legislation.

Table 1: Participant characteristics.

| | n | % |
|---|---|---|
| **Gender** | | |
| Men | 18 | 75.0 |
| Women | 6 | 25.0 |
| **Ethnicity** | | |
| NZ European | 6 | 25.0 |
| Māori | 14 | 58.3 |
| Pasifika | 3 | 12.5 |
| MELAA | 1 | 4.2 |
| **Leave status** | | |
| Yes | 18 | 75.0 |
| No | 6 | 25.0 |
| **Amount of leave used (hours)** | | |
| 0 – 2 | 6 | 25.0 |
| 2 – 5 | 0 | 0.0 |
| 5 – 10 | 4 | 16.7 |
| 10 – 15 | 1 | 4.2 |
| 15 – 20 | 5 | 20.8 |
| 20+ | 8 | 33.3 |
| **Smoking status** | | |
| Smoker | 10 | 43.5 |
| Non-smoker | 13 | 56.5 |
| **Weight status** | | |
| Normal weight (18.5 – 24.9 kg/m$^2$) | 17 | 70.8 |
| Overweight (25.0 – 29.9 kg/m$^2$) | 6 | 25.0 |
| Obese ($\geq$ 30.0 kg/m$^2$) | 1 | 4.2 |

*Note:* NZ = New Zealand; MELAA = Middle Eastern, Latin American, and African.

The most common primary diagnosis was schizophrenia (n = 21, 87.5%). The primary diagnosis of the other three participants was schizoaffective disorder, major depressive disorder, and bipolar affective disorder. Ten participants did not have a secondary psychiatric diagnosis (41.2%), though 12 had a substance use disorder (50%), two had post-traumatic stress disorder (8.3%), one had attention deficit hyperactivity disorder (4.2%), one had a history of depression (4.2%), and another had schizotypal personality disorder (4.2%).

With regards to antipsychotic medication, 14 (58.3%) participants were taking Clozapine, 11 (45.8%) were taking atypical medication (e.g., Olanzapine, Risperidone, Quetiapine, Paliperidone, Aripiprazole), four (16.7%) were taking mood stabilisers (Lithium, Sodium Valproate), two (8.3%) were taking antidepressants (SSRIs, Venlafaxine), two (8.3%) were taking benzodiazepines (Lorazepam, Diazepam, Clonazepam), and seven (29.2%) were taking other psychiatric medication. Six (25.0%) participants were taking multiple types of antipsychotic medications.

Nine participants had no comorbid physical health conditions (37.5%), whereas eight had metabolic risk factors (e.g., hypertension, hyperlipidemia) (33.3%), three had musculoskeletal afflictions (e.g., arthritis, chronic joint pain) (12.5%), three had breathing troubles (e.g., sleep apnea, asthma, emphysema) (12.5%), two had polycystic ovary syndrome (8.3%), two had hyperthyroidism (8.3%), two had low iron/anemia (8.3%), and three reported other conditions (12.5%).

### 3.2. Physical activity and motivational characteristics

Descriptive statistics for the participant physical activity duration and motivation scores are presented in Table 2. Most physical activity occurred via walking. Overall, the participants scored highest for intrinsic motivation and identified regulation, but integrated regulation was also scored highly.

All participants reported participating in at least one hour of physical activity daily and easily exceeded current global recommendations for physical activity participation (Bull et al., 2020). We note that many of our participants provided information that did not sufficiently account for 24 hours. Recall is understood to be low in this population, and for this reason the SIMPAQ includes aids to maximise recall (e.g., the interviewer totals the hours recall as the interview progresses). This is also reflected by the SIMPAQ guidelines that indicate accounting for between 18 and 30 hours is sufficient recall (Rosenbaum et al., 2020).

Table 2: Physical activity and motivation descriptive statistics.

| | M | SD |
|---|---|---|
| **Self-reported physical activity (hrs/day)** | | |
| Walking | 2.2 | 2.3 |
| Exercise and sport | 0.5 | 0.4 |
| Other | 0.3 | 0.6 |
| Moderate-vigorous | 2.7 | 2.3 |
| **Motivation to be active (scale)** | | |
| Intrinsic motivation | 3.1 | 0.7 |
| Integrated regulation | 2.7 | 1.1 |
| Identified regulation | 3.1 | 0.7 |
| Introjected regulation | 1.9 | 1.1 |
| External regulation | 1.5 | 1.2 |
| Amotivation | 0.4 | 0.6 |
| Relative Autonomy Index | 11.7 | 5.0 |

### 3.3. Association between motivation and physical activity

Results from the correlation analyses are presented in Table 3. All correlations between the different physical activity types and the RAI score were negligible (Spearman's rho < 0.3). The correlations between total moderate-vigorous physical activity and each of the six motivation subscales were also negligible (Spearman's rho < 0.3). However, participation in exercise and sport was positively correlated with both intrinsic motivation (Spearman's rho = 0.356) and identified regulation (Spearman's rho = 0.391), albeit a weak association. All other correlations between physical activity types and the motivation subscales were negligible (Spearman's rho < 0.3).

## 4. Discussion

We found high levels of self-reported physical activity, primarily in the form of walking, in our sample of inpatients with SMI at a mental health care facility in New Zealand. Although there was a negligible association between total moderate-vigorous physical activity and all indicators of motivation to be physically active, volitional physical activity (i.e., exercise and sport) was weakly associated with both intrinsic motivation and identified regulation. Despite several limitations, our findings have important implications for the development and delivery of physical activity interventions for people experiencing SMIs and are admitted to mental health care facilities.

The levels of physical activity reported in our sample far exceeded that in the general population in New Zealand (Ministry of Health - Manatū Hauora, 2020; Sport New Zealand - Ihi Aotearoa, 2020). This contrasts with the existing international evidence for people experiencing SMI, who typically fall below general population norms (Schuch et al., 2017; Stubbs et al., 2016). Indeed, even compared to previous research within the same population (Huthwaite et al., 2017), physical activity levels were significantly elevated. Although this is almost certainly partly due to selection bias in our sample from voluntary recruitment, it is important to note that previous meta-analyses did not include data from New Zealand where clinical care norms are rapidly evolving to be more inclusive of physical activity 'prescription' (Schuch et al., 2017; Stubbs et al., 2016). Indeed, in the region from which our sample was taken there has been an increasing focus on embedding physical activity in the usual care provided by mental health care practitioners (Capital and Coast District Health, 2015).

Another potential reason that our results differed to previous research in this population lies in the data capture method. The SIMPAQ, being delivered via an interview and designed to provide increased hourly accountability, was more sensitive to smaller incidental physical activities as compared to the self-report measure used previously (Huthwaite et al., 2017). Further, specific changes in the context since the previous study were reported by staff working at the facilities, including new programmes facilitated by on-site cultural support groups and compulsory morning 'outside' time in some units that were not in place during the previous study.

Research assistants reported that some participants were also walking outside while using electronic cigarettes (i.e., to 'vape'), an activity that was not permitted during Huthwaite et al.'s (2017) study. Staff also anecdotally reported that participants 'pacing' inside the unit was a common form of physical activity, which might have been missed by less sensitive self-report physical activity measures. It is highly likely that our results reflect a mixture of these recent institutional and regulatory changes. Finally, we note that self-report methods for PA are subject potential reliability issues (Firth et al., 2018) regardless of the population being studied.

The high levels of physical activity participation in our sample may partially explain the limited associations we found with motivation to be active. Despite the ongoing conjecture in the international literature, most studies report a much stronger cross-sectional association between physical activity and motivation to be active when compared to our study (Owen et al., 2014; Teixeira et al., 2012). However, all prior studies comprised fewer active participants. The geographical context of the facilities – located on a large campus one kilometre distance from the nearest shops – may have resulted in patients with appropriate leave status accumulating physical activity opportunistically through walking as a means of getting somewhere rather than as a deliberate exercise strategy. It is also possible that participants in our study had a substantial volume of physical activity embedded in their daily mental health management plan, and that direct supervision of this within an inpatient setting increased their participation irrespective of their motivation. A case in point is the compulsory daily outdoors time - characteristic of controlled motivation - which existed at the time of data collection in some of the units.

Table 3: Spearman's rho correlations between physical activity and motivation to be active.

| **Motivation subscale (BREQ-3-PA version)** | **Self-reported physical activity (hrs/day)** | | | |
|---|---|---|---|---|
| | **Walking** | **Exercise and sport** | **Other** | **Moderate-vigorous** |
| Intrinsic motivation | 0.034 | 0.356# | 0.179 | 0.079 |
| Integrated regulation | 0.257 | 0.194 | -0.096 | 0.296 |
| Identified regulation | 0.171 | 0.391# | 0.062 | 0.293 |
| Introjected regulation | 0.038 | 0.207 | 0.027 | 0.053 |
| External regulation | 0.001 | 0.129 | 0.077 | 0.019 |
| Amotivation | -0.293 | -0.031 | -0.105 | -0.242 |
| Relative Autonomy Index | 0.244 | 0.117 | 0.056 | 0.284 |

*Note:* #Denotes a low correlation according to established thresholds for effect size (Hinkle et al., 2003).

This may partly explain why physical activity was not strongly associated with autonomous motivation in this study. Of note, previous studies of physical activity motivation in the SMI population have not been conducted specifically within forensic inpatients with limited leave.

Thus, structured physical activity offered to our participants as part of usual care combined with more limited autonomy than the general population could have increased physical activity via mandated participation. Although this potentially has physical health benefits for individuals with SMI (Correll et al., 2017; Olfson et al., 2015; Swaraj et al., 2019; Vancampfort et al., 2017), if autonomy is compromised, it may also have a negative impact on their immediate mental health and their sustained participation in physical activity. It is now well established that positive experiences of physical activity are critical for improving mental health and facilitating ongoing participation in people experiencing SMI (Bull et al., 2020; Firth et al., 2016). An important part of this is providing participants with the opportunity to initially choose physical activity options that they find appealing (Collado-Mateo et al., 2021). Added to this, of course, is the fact that participants' recently increased use of electronic cigarettes might have contributed to increased physical activity, this balance of different health behaviours is clearly a delicate one.

Despite the evidence for the mental health benefits of walking (Kelly et al., 2018), its overwhelming contribution to total physical activity and underwhelming association with motivation in our results suggests that it may not have been the activity of choice for our sample. In contrast, it appears that the intrinsic motivation our study participants had to engage in physical activity did contribute to their participation in exercise and sport. Similarly, our results for identified regulation indicate that the participants attached personal importance to being physically active and this was also a determinant of their engagement in physical activity. These findings highlight the importance of focusing on enjoyment and personal values, particularly via environmental and/or experiential interventions, when attempting to motivate people with SMIs to be physically active (Rhodes et al., 2009). Our results also add support for the qualitative findings from previous research with regards to high levels of autonomous motivation in this population (Every-Palmer et al., 2018).

However, our results also contextualise and bring into question the relative importance of motivational approaches for effective promotion of physical activity in SMI inpatient settings. Specifically, as we have surmised above, our findings indicate that the high levels of physical activity participation in our sample were not particularly driven by individuals' motivation to be active. Furthermore, implementing an intensive strategy to improve motivation at an intrapersonal level, such as motivational interviewing, in isolation is likely to have limited scalability and cost-effectiveness in this population group (O'Halloran et al., 2014). Rather, it is more likely that concurrently addressing multiple factors across the socio-ecological model will directly improve physical activity levels and indirectly influence motivation levels (e.g., changing socio-cultural norms to enable safe access for inpatients with SMI to a broad range of community sports) (O'Halloran et al., 2014; Solar & Irwin, 2010). This does not preclude individualised approaches to address motivation, but there is a clear need for further research to understand its role in SMI inpatient settings.

Further research should include longitudinal and intervention studies to overcome the cross-sectional limitations of our study and establish the temporal relationship between motivation and physical activity participation in SMI inpatients. Based on our findings, this may be particularly pertinent when considering the transition that occurs when an inpatient with SMI is discharged into the community. Although motivation did not appear to be a critical factor for engaging in a large amount of physical activity in a highly structured inpatient setting, it may become more important as an individual moves to an environment that is likely to be inherently less supportive. For example, the social and built environment within which individuals will live is fundamentally different upon discharge, meaning many habits formed during an inpatient stay may not transfer unless individuals are appropriately prepared and supported to make this transition. Despite this, our results indicate that even people without a large amount of leave from the facility were engaged in physical activity levels well above national norms (Ministry of Health - Manatū Hauora, 2020; Sport New Zealand - Ihi Aotearoa, 2020). How well this is sustained after discharge is yet to be ascertained and warrants further investigation. Importantly, as is the case in other areas of health within Aotearoa and previous research in this population, Māori were overrepresented in our sample. As such, any interventions that are developed should at least be culturally responsive or ideally based on cultural knowledge that reflects the target population (e.g., Mātauranga Māori).

There were several other limitations to our study that should be addressed in future research. As previously mentioned, one limitation is the small sample size. Participants represented only 26% of the total number of patients in these forensic and rehabilitation services. Recruitment for such research is historically challenging within forensic and rehabilitation services, and our participation rates were similar to previous research in the same population (e.g., Huthwaite et al., 2017). Therefore, even though our participants were highly active, they were not representative of the larger population of patients within these services. It is possible that those who chose not to participate did so in part because they were not active, or participation precluded by failing to meet inclusion criteria at the time of recruitment. The small sample size prevented more nuanced and adjusted analyses.

Additionally, the small sample size is attributable to the exploratory nature of our study, the uniqueness of the target population, and challenges in obtaining complete measurement responses (e.g., due to participant recall). The use of objective measurement devices would address the widely recognised concerns about the validity of self-report physical activity measures, particularly in this population group whose recall capacity is often compromised (Sallis & Saelens, 2000). Although the SIMPAQ was specifically developed for people with SMI with these limitations in mind and has been validated internationally across multiple settings (Rosenbaum et al., 2020), our sample had particularly high attrition. Future research should ensure that measures are in place to improve data completion rates. For example, participants could be asked about a specific day (as opposed to a 'over the last seven days') or alternative measurement methods could be used (e.g., physical activity diary). Subjective reports can be triangulated with objective with objective recording through the use of activity trackers.

Furthermore, sampling from numerous inpatient facilities would help to increase sample size, as well as allow for comparisons between facilities to identify areas of apparent strength and/or weakness. Finally, assessing only motivation limited the ability to draw firm conclusions on other determinants of physical activity participation in the target population group. Assessing other psychological constructs, such as barriers/facilitators to physical activity may help identify what intrapersonal, interpersonal, and environmental factors need to be addressed.

In summary, our sample was a highly active group, but we found limited evidence of an association between physical activity participation and autonomous motivation to be physically active. However, the patient management methods in place in this context are likely to have impacted participants' autonomy, which would have influenced this association. We believe that autonomy-supportive motivational interventions based on motivational theory do have a place in forensic and rehabilitation services, but considering the restrictions in place in such settings, these are likely to look different in design as compared to those used in the general population. Regardless, any motivational work should leverage the perceived enjoyment and value of being physically active to engage people in exercise and sports of their choice. We also acknowledge that physical activity and exercise, while crucial to the improving the physical health of people living with serious mental illness, other factors also significantly contribute to health and well-being, including nutrition and smoking abstinence. As such, any efforts to improve the health of this population should consider multiple health behaviours besides physical activity. Future research involving larger samples, exploring changes over time, assessing other constructs, and/or involving comparisons between facilities or individuals in the general population is warranted.

## Conflict of Interest

The authors declare no conflict of interests.

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# Does a combined swimming pool and open water education programme for children develop adaptable water safety competencies?

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## ABSTRACT

*Most learn-to-swim programmes are undertaken in one location (often a swimming pool), which is potentially less effective than learning across a range of aquatic places and contexts. Water safety education delivered in multiple environments may improve skill development and transfer. We investigated whether a combined pool and open water programme improves children's knowledge and skills. Sixty-six children (7 – 11 years old, 34 males, 32 females) participated, of which 40 undertook a 5-day education intervention (two days in a pool, one day each at a harbour, beach, river) and 26 were controls. The skills taught and assessed were: continuous 5-minute swimming, floating and treading water, underwater swimming, and a water safety quiz. Skill competency was assessed in a harbour before, immediately after, and approximately one month after the education programme. The number of children in the education group demonstrating high competency increased after the intervention (i.e., quiz = +20%, swim = +22%, floating/treading water = +37%, underwater swim = +29%) Furthermore, performance of the skills was generally improved when combined and adapted in a self-rescue transfer activity. The control group also improved in 3 out of 4 of the tasks, however their knowledge (quiz) performance decreased. Our findings indicate that teaching children water safety in several aquatic environments improved skill competency and transfer. Water safety education should be undertaken in a range of representative environments to promote skill transfer and thereby reduce the risk of drowning in open water. Education providers should consider opportunities to extend pool-based programmes to include exposure to open water environments.*

## 1. Introduction

Aotearoa, New Zealand is home to a plethora of different aquatic environments, many of which offer attractive recreational opportunities. However, it is important that people are properly educated to access and utilise these resources safely. Historically, it has been assumed that learn-to-swim education conducted within swimming pools is sufficient to develop aquatic competencies that prevent drowning (Brenner et al., 2006; Guignard et al., 2020; Stallman et al., 2017). However, despite this widely-held belief, a large number of drownings continue to occur in open water environments (World Health Organization,

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2015). It is possible that just learning foundational swimming strokes in a pool is insufficient to safeguard people from drowning (Hindmarsh & Melbye, 2011; Carey, 1993). Perhaps surprisingly, the influence of practice environment on the learning of water safety knowledge and skills has received very little attention to date (van Duijn et al., 2021). We need to understand how best to expose learners to different aquatic environments as they navigate this journey to water safety competency (Button, 2016).

In most developed nations, the education of swimming and water safety skills is typically undertaken in swimming pools (Chan et al., 2020; Di Paola, 2019; Stevens, 2016). Swimming pools provide a seemingly 'ideal' setting for education and competency assessments as the environmental conditions are relatively comfortable, stable, and reproducible (i.e., water temperature, currents, waves, depth, etc.). However, Brenner et al. (2006) argue that traditional measures of pool swimming ability are not the same as evaluating the skills needed to prevent drowning. In practical terms, a child may believe that if they can swim 25 metres in a pool then they can swim that distance to a pontoon at a lake. Or, perhaps because they can dive into a pool safely, then they can also dive safely from a jetty into the ocean. Unfortunately, such comparisons are made invalid and potentially dangerous by numerous environmental factors that can make tasks in open water much more challenging.

Motor learning is not just about reproduction and retention of certain movement patterns. Instead learning requires skills to be transferable which demands sensitivity to one's own action boundaries – the limits of our movement capabilities – as well as knowledge of the environment (Button et al., 2021; Seifert et al., 2018). Pertinent to the issue of where water safety education should be undertaken, knowledge of the environment refers to a learner's ability to identify specifying and non-specifying information (Seifert & Smeeton, 2020). Specifying information (e.g., propulsive or resistive force, etc.) is directly related to the task goal and can help the learner to calibrate their movements well. Whereas non-specifying information (e.g., temperature, depth, etc.) is still important but more ambiguous in that it does not directly inform how the learner should move. Affordances are opportunities for action offered by the environment (such as 'catching a wave') that are relative to the individual's abilities. Exposure to such affordances during practice empowers learners to exploit them optimally (Oppici & Panchuk, 2022). Skill transfer is the capacity of motor behaviours to be adapted to another task or novel situation (Button et al., 2021). Transfer is multifactorial and nested within different continua (i.e., near/far; horizontal/vertical; and specific/general transfer). The specific-general transfer continuum was neatly illustrated by Oppici and Panchuk (2022) within a pertinent example. They suggested that specific transfer from a pool to open water may be observed as an experienced pool-swimmer typically adopts a streamlined position in open water to minimise drag and propel themselves forcefully in a desired direction. As the swimmer practices in open water, they may also learn to utilise non-specifying information invoking a more general form of transfer (or 'attunement to surrounding affordances'). Hence specific and general forms of skill transfer interact which helps us to understand why some water safety skills (like floating or swimming) in open water can be challenging for pool-trained learners.

Hence, robust assessments of water safety competency should account not only for skill improvements and retention, but also for skill transfer (van Duijn et al., 2022). Knowing that a child can swim in a pool has limited relevance if they cannot adapt this skill to be performed in open water. This is because introducing more variability in the water conditions (such as waves) of a swimming pool demands transferable swimming skills. Indeed, Kjendlie et al. (2013) showed that when open water-like conditions (i.e., waves) are simulated in a pool, the levels of skill competency are markedly lower. In their study, 66 children (11-years old) performed identical tests in two different environments: a calm swimming pool and a simulated wavy environment. The tests performed in the waves clearly showed a performance decrement (between 9 and 14% longer time to complete the swimming test and 21%, 16%, and 24% lower scores for rolling entry, diving, and floating tests, respectively). The authors cautioned that "[children] should not be expected to reproduce swimming skills they have performed in calm water with the same proficiency in unsteady conditions during an emergency" (Kjendlie et al., 2013, p. 303). To our knowledge there is currently no data published about children's competencies when tested in open water nor how different practice environments can facilitate skill transfer.

New Zealand's 'Water Skills for Life' (WSFL) initiative was launched following a nationwide review which exposed large variation in water safety education programmes across the country (Stevens, 2016). WSFL lists a range of 15 water competencies that children are expected to have learnt by year 8 of high school (see Figure 1). For example, 13-years-old children should be able to float and tread water independently for up to 5 minutes, to swim underwater for up to 5 seconds, and to be able to swim for up to 100 m (up 5 minutes) using whichever stroke/s they prefer. Importantly, WSFL also emphasises the need for children to develop knowledge and skills associated with open water environments and local hazards (Figure 1).

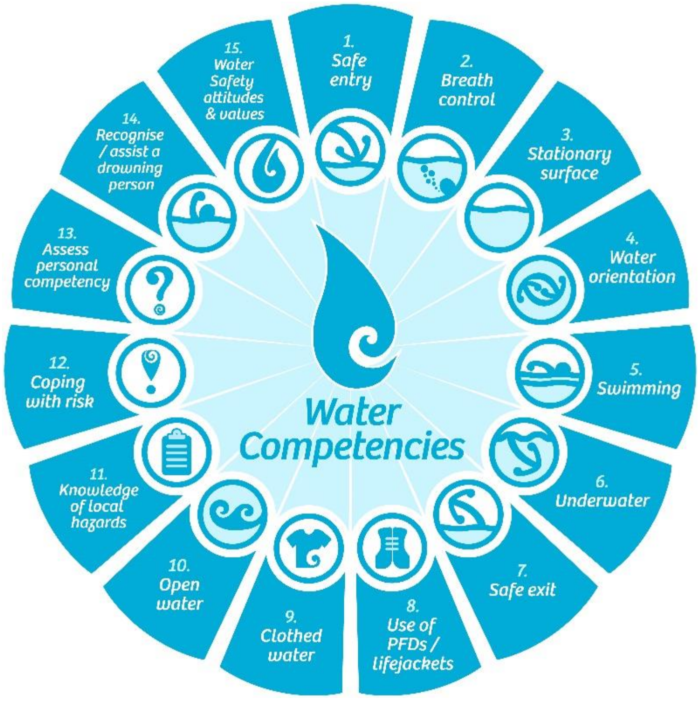

Figure 1: Fifteen water safety competencies that form the foundation of the Water Skills for Life Programme. To be reproduced with permission of Drowning Prevention Auckland.

Recent studies by Button and colleagues (2017; 2020) have provided initial data about some of the WSFL competencies of New Zealand children. Button et al. (2017) tested 48 children (7 – 11 years old) in swimming pools. The percentage of children achieving a high competency rating at pre-test was typically low. The children's knowledge about risk in different environments was particularly poor with only 15% performing well at a pre-test quiz. Furthermore, 62% of children could not swim 100 m (or up to 5 minutes) continuously in a pool. In Button et al.'s (2020) follow-up study the water safety competencies of 98 children (7 – 11 years old) were tested in a swimming pool before, immediately after, and three months after receiving a three-day intensive education programme (delivered in a river, at a beach and in the harbour). At pre-test, once more a typically low competence level was found with less than 50% of children achieving a high level of water safety competence. However, after the 3-day intensive program, competency in each of the six tasks assessed had increased with up to 80% of participants completing the tasks unassisted. The three-month retention of these skills was also generally high (i.e., competency levels were either maintained or improved). Whilst these studies are informative it is important to acknowledge that the children were assessed in swimming pools, it needs to be established how robust these skills are when performed in an open water environment.

In summary, a swimming pool is a relatively safe aquatic environment to begin educating children about water safety. Skill transfer is sensitive to surrounding conditions at the time of transfer and is highly dependent on activities undertaken during training. However, there is a lack of evidence to show how best to develop transferable competencies into open water environments. Theoretically, practicing in a range of aquatic environments exposes learners to a rich 'aquascape of affordances' promoting specific and general skill transfer. Hence, we examined whether education undertaken in various environments improves water safety competency and the capacity to adapt such skills in a simulated survival scenario. We expected a combined pool and open water education programme to improve children's water safety competencies, as well as to develop transferable skills that might be adapted to an emergency scenario.

## 2. Methods

### 2.1. Participants

The target sample size was 96 participants, based upon a conservative population estimate of approx. 500,000 (New Zealand children aged 7 – 11 years), confidence level of 95%, and confidence interval of 0.1. Exclusion criteria included any recognised learning difficulties, or existing health conditions (e.g., injuries, severe asthma) that may put the participant at risk during testing. A two-week period of advertising (i.e., website, social media, posters) resulted in 116 registrations of interest. All registered children were invited to the competency screening test (see Procedure) at a public swimming pool. The screening test was necessary to exclude potential participants who would require one-on-one supervision (i.e., non-swimmers or very anxious children) and any participants that were unable to complete all scheduled tests (n = 36). Eighty children successfully passed the screening test and were eligible to participate. These children and at least one parent or guardian provided written informed consent to participate in the study.

The 80 registered participants were allocated into two groups that were scheduled to receive the same water safety education programme. Group 1 consisted of 40 children (20 males, 20 females). Group 2 initially had 40 children, however, due to increased restrictions imposed by an unanticipated change in Covid-19 alert levels, Group 2 were unable to complete the education programme and this group took no further part in the study. However, 26 children from Group 2 did complete two baseline assessments to contrast with Group 1. Hence, data from 66 children (Education Group: n = 40, Control Group: n = 26) were collected and presented in the results (Table 1).

Table 1: Descriptive statistics by group.

| | | Age (years) | | Height (cm) | | Weight (kg) | |
|---|---|---|---|---|---|---|---|
| **Group** | **n** | ***M*** | **SD** | ***M*** | **SD** | ***M*** | **SD** |
| **Education** | | | | | | | |
| Female | 20 | 9.17 | 1.3 | 140 | 11.7 | 39.6 | 15.2 |
| Male | 20 | 9.87 | 1.3 | 141 | 8.5 | 35.4 | 8.8 |
| **Control** | | | | | | | |
| Female | 12 | 9.48 | 1.5 | 143 | 18.1 | 40.2 | 16.7 |
| Male | 14 | 9.89 | 1.1 | 143 | 8.5 | 39.6 | 10.3 |

### 2.2. Procedure

Ethical approval was obtained from the host institution's Human Ethics Committee prior to the study commencing (Ref: 21/138). A competency screening test was included for safety and logistical reasons. The screening test required participants to complete a basic physical activity questionnaire for children and a basic water-skills assessment conducted in an indoor swimming pool. The water skills included: entry into deep water from side of pool, float on back for 30 seconds, submerge 1 m to retrieve an object, swim back to poolside and safely exit the pool. Each child's performance in the screening test was visually assessed by a qualified aquatic educator who was in the water within arms-reach of participants. The children were permitted to wear a lifejacket at any time in the screening test if they wished to.

Participants were required to visit the testing location (a public beach beside a harbour channel) for competency assessments on three separate occasions, each 5 – 7 days apart. During each visit of approximately 60 minutes duration, participants were asked to perform a water safety skills test battery (see Table 2). The tasks required the participants to perform several physical tests of water safety skills unaided[1] as well as assessments of risk perception and knowledge in the form of a quiz. Tasks 1 – 4 were undertaken separately in the first and second testing session. For the third session,

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[11] Although children undertook the 4 tasks 'unaided' they were supervised for all tasks by the researchers to ensure their safety and comprehension of the task goal.

Table 2: Series of tasks presented independently to participants before and after the education programme, and in combination as part of a Transfer test.

| **Task** | **Task description** | **Assessment (grades 0 – 5)** |
|---|---|---|
| **Quiz*** | A series of multi-part questions prompted by pictures of various aquatic environments (e.g., ocean, river, lake, harbour). The knowledge tested included:<br>1. Understands how various open water conditions influence risk<br>2. Knowledge, understanding and attitude towards water safety rules, hazards, and risks<br>3. Recognise an emergency for yourself or others<br>4. Know how/who to call for help | 0 = 0-2 correct<br>1 = 3-6<br>2 = 7-10<br>3 = 11-13<br>4 = 14-17<br>5 = 18-20 |
| **Floating** | The floating task took place in deep water where the children could not reach the ground to support themselves. Participants were required to enter the water safely and then to float on their back for one minute. If they accomplished this, they then had to tread water for four further minutes. Once five minutes was completed, the participants had to call for help with one hand in the air before exiting the water. | 0: No attempt or enters water unsafely (i.e., jumps without checking)<br>1: Cannot complete back float (< 30 s), no treading water<br>2: Cannot complete back float (< 60 s) or treading water (< 60 s)<br>3: Completes back float, partial completion of treading water (< 120 s)<br>4: Completes back float, partial completion of treading water (> 120 s), or no help signal<br>5: Completes back float, treading water (240 s), signals for help, and exits safely |
| **Underwater swim** | The submersion task took place in semi-deep water (about 1.5 m deep) approximately 5 m from shore. Participants were asked to hold their breath and to submerge completely and then swim through three large, submerged hoops to retrieve a bright diving ring situated 1 m, 2 m, and 5 m away. The diving ring was held by a lifeguard under the water. Once participants had retrieved the ring, they gave it back to the lifeguard and then got out of the water. The use of swimming goggles was optional for this task. | 0: No attempt, or does not submerge face<br>1: Swims through 1 m ring in +1 attempt<br>2: Swims through 1 m ring in one attempt (without surfacing for breath)<br>3: Swims through 2 m ring in +1 attempt<br>4: Swims through 2 m ring in one attempt (without resurfacing)<br>5: Swims through 5 m ring in one attempt (without resurfacing) |
| **Swim** | Several floating buoys were attached by a 12.5 m long rope in water of approximately 2 m depth (about 15 m from the beach). Ten kg anchors were attached to the rope at each end to secure its position in the water. The rope and buoys created a temporary swimming 'channel' in the water. The children were transported by kayak to one of the buoys. They then got in the water unsupported and were asked to swim continuously beside the rope on their right for whichever came first of up to 5 minutes or for 8 lengths (100 m). They were instructed not to touch the rope or ground if possible and that they could use whichever stroke they preferred. The use of swimming goggles was optional. When the child wanted to finish the task or completed it successfully, they swam to a nearby kayak. | 0: No attempt<br>1: 0 – 25 m aided<br>2: 0 – 25 m unaided<br>3: 25 – 50 m unaided<br>4: 50 – 75 m unaided or up to 5 mins<br>5: Able to swim continuously for 100 m without assistance (< 5 mins) |
| **Transfer/ self-rescue** | Simulated survival scenario in which a combination of task elements described above were performed in sequence (i.e., quiz, floating/treading, underwater swim, swim,). First participants had to choose the furthest distance they felt that they could swim from 5 brightly-coloured buoys positioned 15 m, 30 m, 50 m, 100 m, 150 m from the jetty. The researcher then paddled the participant to the chosen buoy in a two-person kayak. A hypothetical scenario was described to participants that their kayak was about to be overturned by a wave and they had to act to rescue themselves. A lifeguard also remained at arms-reach of participants during the scenario with a buoyancy aid if required. Upon their return to the jetty, participants then completed the knowledge quiz with questions about the activity they had just undertaken. During this scenario participants wore a wetsuit under some light clothing (i.e., old jumper, trackpants, and trainers). | For the transfer activity, each of the 4 tasks described above (Floating, Submersion, Swim, Quiz) was embedded within the simulated survival scenario. The same criteria used above was applied to rate the participants performance at each task (out of 5). |

*Note:* Comprehensive risk management and analysis of the feasibility of undertaking these assessments in open water was undertaken in advance (van Duijn et al., 2022). *Participants could provide up to 20 correct answers.

all four tasks were undertaken in series as part of a mock self-rescue scenario. All sessions were video recorded from the shore (distance of between 5 – 20 m away depending upon the task) to enable retrospective cross-checking of the assessor's ratings.

Thorough risk assessments for all activities were undertaken in advance, and the health and safety of researchers, volunteers and participants was prioritised at all times. The weather and water conditions were monitored closely, and strict criteria were applied in order for outdoor sessions to proceed (i.e., ambient temperature no less than 10°C, within 2 hours of high tide, wind strength no greater than 50 k/hr). Close supervision was provided at all times during testing by experienced staff with valid lifesaving and first aid qualifications. No fewer than six supervisory staff (four in the water, two at water-edge) closely monitored the participants' behaviours. Also, no more than eight participants were allowed in the water at the same time (i.e., supervisor to participant ratio of 1:1.3). Participants were required to wear a wetsuit at all testing sessions for their own comfort.

In the week between the first two competency assessments, the education programme was conducted (see details in Table 3). The first two pool-based education days were run by swimming school educators at a private pool. Days 3 – 5 were run in different open water locations by outdoor education providers who were experienced at delivering such programmes for children. An important feature of the education programme that was developed for this research project was the focus on transferable skills and how to adapt them to different aquatic environments (Guignard et al., 2020). For example, a key emphasis for the swimming pool education sessions was on contrasting differences between the pool and open water. Children also practiced skills in the pool that would be helpful for immersion in different environments such as safe entry and exit, floating, treading water, and self-rescue techniques. When the children progressed to the open water sessions, they were reminded of the knowledge and practical skills they had acquired in the swimming pool.

At the completion of the competency testing, the education group participants were asked to complete a feedback questionnaire together with a parent or caregiver. The questionnaire contained 10 items with a mix of short, open answer questions, and closed, Likert-scale type responses.

### *2.3. Data analysis*

Each participant was allocated a unique identifying code for the purposes of organising data and protecting anonymity. For the pre-test, post-test, and transfer tests each participant's water safety competencies were visually assessed and recorded manually by one of four researchers. The competency demonstrated for each skill was rated on a 6-point Likert type scale, based on a previously validated toolset (Button et al., 2020). The assessors observed participants in small groups of up to four at a time. Cross-checking of ratings occurred regularly between assessors.

Table 3: Summary details of combined pool and open water environment safety lessons.

| Day | Duration (hours) | Activities | Staff-participant ratio | Equipment | Notes |
|---|---|---|---|---|---|
| **Pool** | 3 | Safe entries/exits, floating, submersion, swim – calm water | 1:6 | Wetsuits, lifejackets, pool noodles, dive rings, fake seaweed | Actual size of group in pool 18 – 20 with 3 educators |
| | | WSFL theory: different aquatic environments, identifying risks | 1:20 | Overhead projector, quizzes, paper, pens | Lesson provided by qualified WSFL educator |
| **Pool** | 3 | Treading water, lifejackets, boat capsize and rope rescues; swim - turbulent water | 1:6 | Wetsuits, lifejackets, ropes (5 m), pool boards, inflatable rescue boat | Actual size of group in pool 18 – 20 with 3 educators |
| | | WSFL theory: what to do in emergencies, who to ask for help | 1:20 | Overhead projector, quizzes, A0 paper, pens | Lesson provided by qualified WSFL |
| **River** | 4 | Survival swim position / floating, river crossings, rope rescues, navigating strainers, understanding current and other dangers | 1:6 | Wetsuits, lifejackets, ropes (10 m), inflatable tube, pool boards, first aid kit, emergency blankets | Groups of 6, overall group size of 40.5 rotating stations set up for each activity |
| **Beach** | 3 | Identifying risks at the beach, signalling for help, flags, rips, sand sculptures, navigating waves, floating, treading water, submersion | 1:10 (theory)<br>1:6 (practical) | Wetsuits, radio, dummy flare, rescue tubes, whiteboard, paper, marker pens | 60 min theory session followed by 120 min practical. Groups of 20 children supervised by 3 lifeguards and a parent/caregiver |
| **Harbour** | 3 | Boats, weather, equipment and tell someone, fitting lifejackets, safe jump entry, capsize from boat, floating, treading water | 1:20 (theory)<br>1:6 (practical) | Wetsuits, rescue boat, personal locator beacon, flare, rescue tubes, whiteboard, paper, marker pens | 90 min theory session followed by 90 min practical. Groups of 20 children supervised by 3 lifeguards and a parent/caregiver |

Furthermore, one assessor viewed video footage of all trials to ensure consistency and accuracy of observations. The inter-rater (Light's Kappa = 0.81) and intra-rater (ICC = 0.83) reliability of 10% of the assessments was confirmed to be 'good' and 'almost perfect agreement' respectively (Hallgren, 2012). Changes in skill competency were based on comparisons between the pre-test and post-test, whereas skill transfer was assessed in terms of whether participants were able to maintain their post-test performance in the transfer task. The post-study questionnaire data was collected in a spreadsheet and descriptive statistics such as means, standard deviations, percentages, and ranges were used to summarise data trends. As the data were ordinal, non-parametric comparisons were run to detect changes over test session (i.e., Kendall's W) or between groups (i.e., Mann-Whitney U). All statistical analyses were undertaken with SPSS for Windows (IBM, SPSS Statistics v. 27.0).

## 3. Results

The main competency data from the education group for each task they were assessed on is summarized in Figure 2. From baseline to post-test, the number of children in the education group demonstrating high competency (rating of ≥ 4) in each task increased (Quiz = +20%, Floating = +37%, Underwater swim = +29%, Swim = +22%) Furthermore, performance in the floating and swimming elements of the transfer task were generally improved from baseline (Figure 2). The statistical comparisons broken down by task are provided in the following sub-sections.

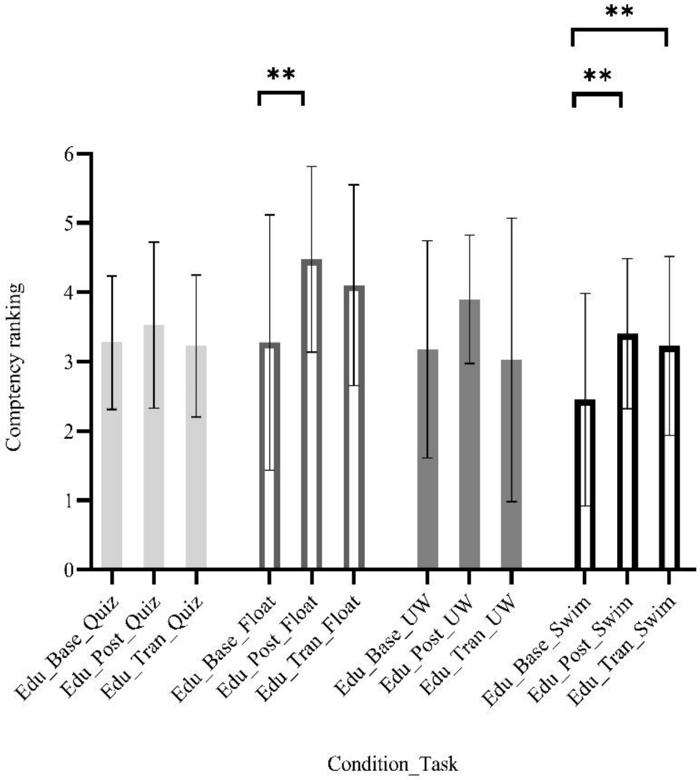

Figure 2: Column chart (means and error bars) of education group competencies for each task. Education group (Edu); Underwater task (UW); Baseline assessment (Base); Post education assessment (Post); Transfer assessment (Tran). $**p < .01$ between groups.

### *3.1. Quiz*

Quiz ratings for the education group were not significantly different over test sessions (W(2) = 0.60, *p* = .089). The post-test ratings (mean = 3.53) did trend higher than both the baseline (mean = 3.27) and the transfer test (mean = 3.23), but these comparisons were not significant (*p's* > .05) (Figure 2).

In terms of the group comparisons, there was no difference between the groups at the first baseline test (Edu = 3.28, Control = 3.42; U = 474.50, *p* = 0.53) (Figure 3). The education group performed significantly better than the control group in the post (second baseline) test (U = 266.50, $p < .001$, $\eta^2 = .17$). It was noted that whilst the education group improved their Quiz ratings from baseline by 8% (mean = 3.53), the control group decreased by 25% (mean = 2.58).

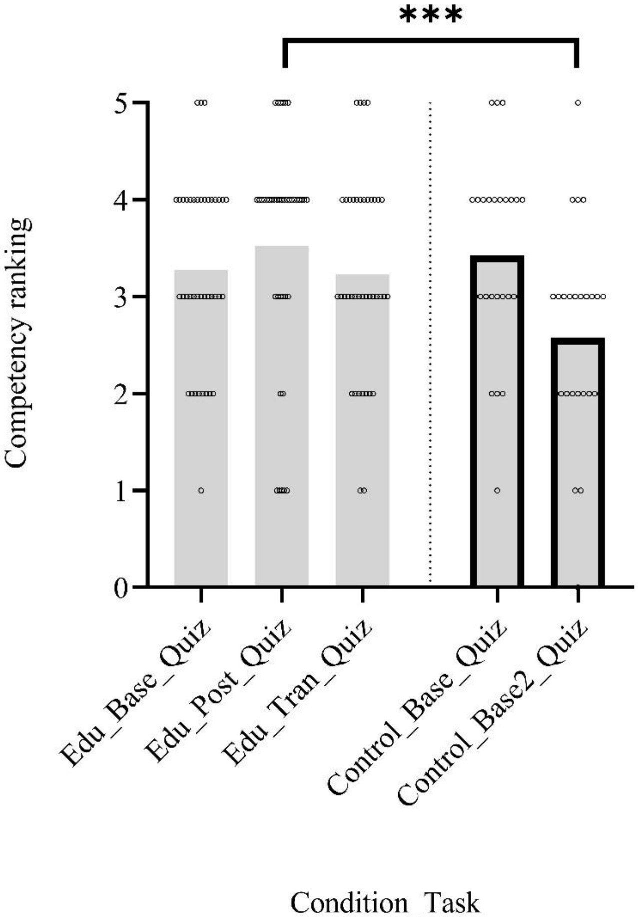

Figure 3: Column (means) and scatter dot plot of Quiz competency for education group (left side/unbordered columns) and the control group (right side/bordered columns). Second baseline test (Base2), which was in essence the 'post-test' for the control group. $***p < .001$ between groups; °individual datapoints.

### *3.2. Floating*

Floating competency assessments were significantly different over time for the education group (W(2) = 0.19, p < .001,). As shown in Figure 2 the post-test ratings (mean = 4.47) were higher than baseline (mean = 3.28). The transfer test (mean = 4.10) also trended higher than baseline, but this comparison was not significant (p = .09).

There were no significant differences between groups for Floating at the first baseline test (U = 452.00, p = 0.33), nor at the second baseline test (U = 440.50, p = 0.17). Figure 4 shows that both groups showed better Floating competency by their second test (wave 1 increased by 36%, wave 2 increased by 14%).

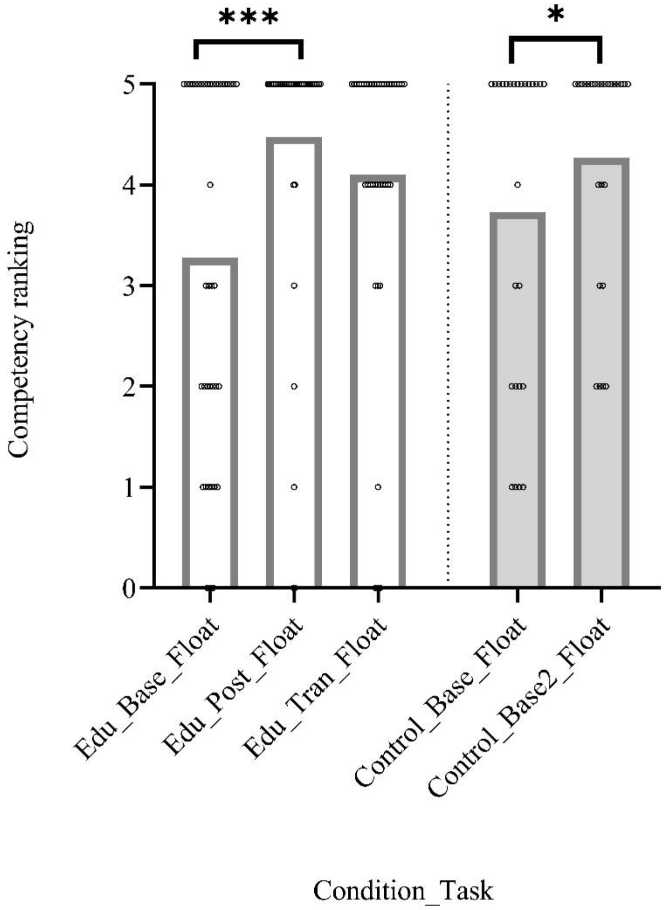

Figure 4: Column (means) and scatter dot plot of Floating competency for education group (left side/bordered columns) and the control group (right side/shaded columns). ***$p < .001$ between groups; *$p < .05$ between groups; °individual datapoints.

### *3.3. Underwater swim*

The Underwater swim ratings were not significantly different over time for the education group (W(2) = 0.06, p = .077). The post-test ratings (mean = 3.90) did trend a little higher than both the pre-test (mean = 3.18) and the transfer test (mean = 3.03), but these comparisons were not significant (*p's* > .05).

There were no significant differences between groups at the first baseline (U = 403.00) nor at the second baseline (U = 508.50) for the Underwater swimming task (Figure 5).

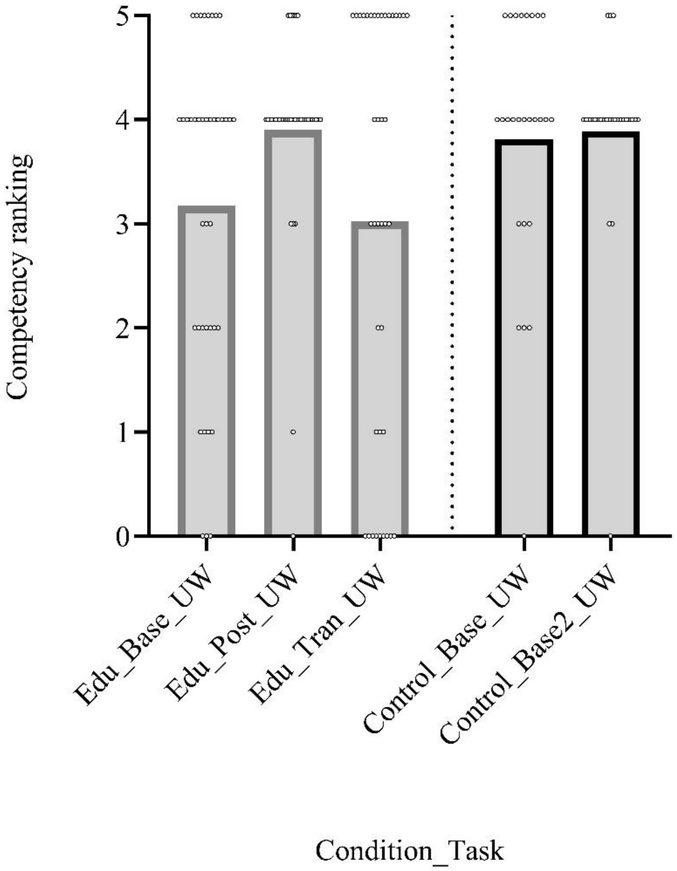

Figure 5. Column (means) and scatter dot plot of Underwater (UW) competency for education group (left side/unbordered columns) and the control group (right side/bordered columns). °individual datapoints.

### *3.4. Swim*

Swim ratings were significantly improved over test sessions for the education group (W(2) = 0.25, p < .001). The post-test score (mean = 3.40) and transfer test (mean = 3.23) were both higher than the pre-test (mean = 2.45) as shown in Figure 2. There were no significant differences between groups at the first baseline (U = 439.50) nor at the second baseline (U = 489.00) for the Swim task (Figure 6).

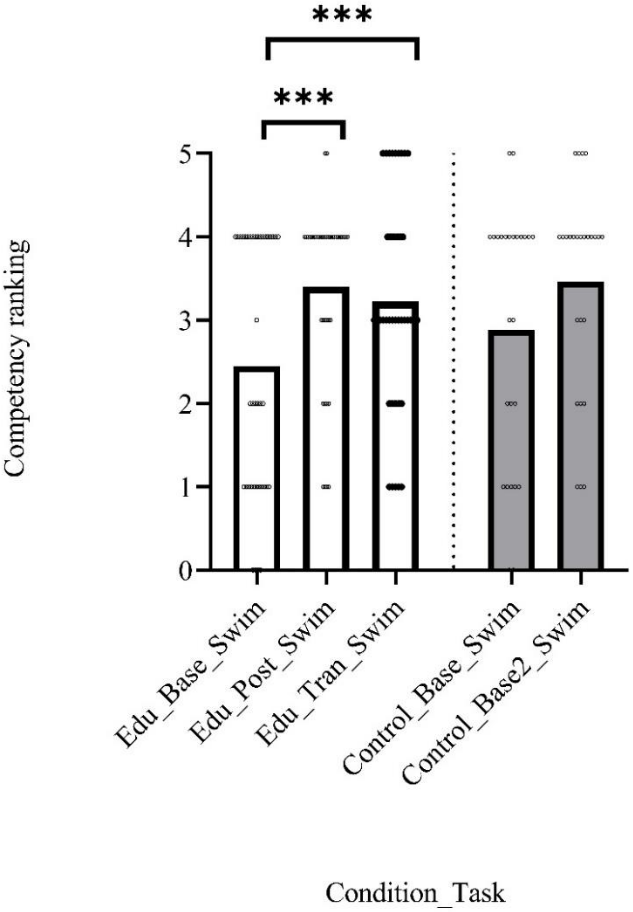

Figure 6. Column (means) and scatter dot plot of Swim competency for education group (left side/bordered columns) and the control group (right side/shaded columns). ***$p < .001$ between conditions; ° individual datapoints.

### *3.5. Participant and caregiver's questionnaire*

Twenty responses to the questionnaire were received overall. For 11 of the returned questionnaires there were multiple children in the family taking part in the study, hence the responses actually represented 35 of 40 children from the education group (87.5%). Summary data are presented in Table 5 for the quantitative statements that required closed-scale responses. There was uniformly strong agreement for each positive statement that described various aspects of the water safety programme.

Table 5: Descriptive statistics for closed-item responses from post-study questionnaire (1 strongly agree – 5 strongly disagree).

| Statement | *M* | SD | Range |
|---|---|---|---|
| Overall, I am pleased with my experiences in the study | 1.1 | 0.31 | 1 – 2 |
| I am likely to recommend a program like this to others | 1.1 | 0.65 | 1 – 4 |
| I am more aware of dangers around natural water environments | 1.1 | 0.36 | 1 – 2 |
| I know how to respond should an emergency occur | 1.4 | 0.60 | 1 – 3 |
| I have developed important water safety skills | 1.4 | 0.36 | 1 – 2 |
| I have more adaptable water safety skills | 1.2 | 0.44 | 1 – 2 |
| I have improved my open water swimming ability | 1.3 | 0.66 | 1 – 3 |

In terms of qualitative data (i.e., free-text responses) the feedback generally supported the quantitative data presented in Table 5. Several of the free-text responses also provided some valuable suggestions to consider. Example quotes are provided below:

1. "My child learned many things from the water safety [study] that are not being taught at school."
2. "The increase in confidence and ability to gauge the safety of her swim environment has been significant."
3. "My daughter felt challenged yet supported. She was reassured by the accessible and thorough explanations."
4. "Thank you, it has made [anonymous] more confident in trying new experiences."
5. "Real life simulations ensure kids appropriately judge their abilities in non-pool scenarios."
6. "This should be an essential part of what we teach our children – alongside swimming lessons."
7. "I do wonder if a Te Reo Māori approach could be layered/added to each context and have a Māori perspective too here in Aotearoa?"

## 4. Discussion

The aim was to better understand how education can improve the water safety competency of children. Specifically, we investigated whether education undertaken in various environments improves water safety competency and the capacity to adapt such skills in a simulated survival scenario. Before discussing the key results, it is important to acknowledge that the study faced several logistical challenges due to an unanticipated change in Covid-19 restriction levels that occurred in the middle of testing. Due to the increase in restrictions concerning social distancing, mask-wearing, and gathering of groups, it was not possible to provide the planned education programme for group 2 (that became the Control Group). Hence the data reported here represents just under half the sample size that we aimed to recruit. Whilst the small sample size is an acknowledged limitation, we still believe the data that was collected provides valuable information that contributes to the general aim of the study.

To answer whether the combined swimming pool and open water education programme improved children's water safety competency it is necessary to compare baseline performance to the post-test data. We found significant improvements for two of the tasks (i.e., Floating and Swim) and small, but non-significant, improvements for the other two tasks (i.e., Quiz and Underwater swim). It is possible that the small size of the education group (n = 40) meant that the improvements in the Quiz and Underwater swim did not reach statistical significance. Future research with a larger number of participants will be required to determine if that interpretation is correct. It may also be the case that the Quiz and Underwater swim tasks received insufficient focus in the education programme to prompt similar improvements to those seen in the Floating and Swim tasks. For the Quiz task, perhaps providing supplemental learning resources may enable learners to improve their knowledge within the short timeframe that the programme was offered (Tipton et al., 2021). In terms of the Underwater swimming task many children were able/willing to submerse their head (i.e., swim through at least one hoop 1 m away which was sufficient to achieve grade 3) but they then struggled to hold their breath and to navigate their swim underwater for up to 5 m (i.e., necessary to achieve grade 5). It seems that greater emphasis on breath-holding and underwater navigation during the education programme may be required. Our previous water safety studies have shown improvements in knowledge and underwater swimming with a similar education study (e.g., Button et al., 2020) but the scale of measurement used in this study was adapted from a 4-point to a 6-point scale of competency. On the basis that there were significant improvements shown in two of the four skills tested, we conclude that the education programme was at least partially successful in improving children's water safety competency.

Another interpretation of the competency improvements we found between baseline and post-test (for the Floating and Swim tasks) is that the children simply benefitted from performing the task a second time (i.e., an order effect). Admittedly, there was some support for this interpretation in that the control group also generally performed better in their second baseline test. However, it was noted that the control group's performance in the Quiz dropped markedly (by about 25%) in the second baseline test. Different questions were asked each time the Quiz was administered so it is possible that the second baseline quiz was more difficult than the first, whereas for the other three tasks the same activities were repeated by the children. As such we should not rule out the possibility that the improvements in competency shown following the programme were not simply due to repeating the same task rather than the education that was delivered. Future research could remedy this issue by having participants complete multiple baseline tests before competency assessments take place.

The other part of the research question concerned whether the education programme would allow children to adapt (transfer) their skills successfully into a simulated survival scenario. To identify whether the combined pool and open water programme developed transferable skills it is necessary to compare the post-test to the transfer test data. Only for the Swim task did children maintain their improved post-test ratings (mean rating = 3.4, 38% increase from baseline) in the transfer test (mean = 3.2, 31% increase from baseline). For the other three tasks, the transfer performance was not significantly different from baseline. Although, transfer performance in each element of the simulated survival task was not markedly different from baseline it was notable that all 40 children completed the scenario successfully and independently. They were able to judge appropriately how far they could swim from a capsized boat in deep water and then able to demonstrate that they could actually swim that distance. They were also typically able to perform other required elements of the scenario such as Floating (n = 37, 93%) and Underwater swimming (n = 27, 67%) as demanded within the scenario they were presented with. Indeed, none of the 40 participants required rescuing or asked to stop the transfer test prematurely. Our interpretation of these apparently conflicting results is that generally the participants *did* develop transferable skills to stay safe. By allowing participants to choose the level of challenge in each element of the transfer test (i.e., how far to swim, how to float, whether to swim underwater, etc.) they set themselves achievable and sensible targets that they knew they could satisfy. Arguably these results demonstrate strong practical relevance in that the children were able to judge their abilities and the conditions well, thereby showing improved knowledge of the environment (Seifert & Smeeton, 2020). However, by allowing participants to self-regulate the level of challenge in the transfer test the competency data arguably do not provide a clear/comparable indication of specific skill transfer from the education programme. Instead, our interpretation is that there is evidence of reasoned decision-making and hence general learning transfer has resulted from the programme. Careful design of transfer tasks in future work is needed to account for the interaction of different types of skill transfer that have emerged (Oppici & Panchuk, 2022).

As well as providing quantitative information about water safety competencies, the post-study questionnaire was a valuable source of information about how the study was perceived by participants, parents and caregivers. The data (e.g., Table 5) indicate that the children generally felt more confident in their knowledge and abilities after the study had concluded. For example, most children agreed with statements that they had improved their open water swimming and knowledge thereby showing better awareness of affordances and when it was safe to use them (Seifert & Smeeton, 2020). Unfortunately, the questionnaire did not require participants to report on specific elements of the study, so it is not clear if it was either the assessments and/or the education programme that boosted their confidence. In future research we intend to explore more thoroughly how the children's emotional engagement (i.e., confidence, anxiety, motivation, etc.) was influenced by the programme. Importantly, participants reported that they enjoyed the study and the various challenges and environments it exposed them to. Free text comments offered by several of the parents/caregivers aligned well with their children's perceptions in that they too valued the opportunity for their children to be educated in this way. Several comments indicated that this programme offered much more than just learning to swim in a pool and that they would like to see such a programme freely available to all New Zealand children.

## 5. Limitations

As well as the limited sample size there are several other limitations that were encountered with this study. We did not collect comparison data from a pool-trained control group which would have allowed us to quantify the influence of educating water safety in different environments. It is also possible that an order effect explains some of the competency improvements found amongst the children in the post-test and transfer task. Additionally, the ratings that assessors made were at least partly subjective and therefore potentially biased towards the education programme. We are investigating means to address such limitations in planned research in the future.

## 6. Conclusions and practical implications

The statistical power of the study was affected by an unanticipated change in Covid restriction levels that meant we were unable to achieve the target sample size. Despite this limitation, 40 children aged 7 – 11 years old received a 5-day water safety education delivered in a pool and several open water locations. The children's water safety competency increased after the programme particularly for the Floating and Swimming tasks. The Quiz and Underwater swimming tasks demonstrated smaller but non-significant improvements. In terms of adaptable skills, all children were able to independently complete a self-rescue task that combined the 4 assessed tasks. The feedback received from participants and parents/caregivers about the programme was very positive. Whilst further investigation is required into the different skills that were assessed in the programme this was a valuable step demonstrating that a combined pool and open water education model is feasible and successful in developing competency. An intensive education programme conducted in a swimming pool and multiple open water locations can effectively develop adaptable water safety competency. Water safety education should be undertaken in representative environments to optimise skill transfer (van Duijn et al., 2022) and thereby reduce the risk of water related injury or drowning.

The following practical implications are recommended for consideration:

1. Water safety competency amongst NZ children is quite variable. Some children are very competent, but others show worryingly low competency levels.
2. Developing collective responsibility across multiple sectors (i.e., water safety organisations, schools, outdoor education providers, parents/caregivers, etc.) is required to improve the water safety competency of Aotearoa's children/tamariki.
3. Parents and caregivers highly valued the opportunity to have their children educated in open water environments.
4. Summer holiday programmes and school camps present important opportunities in which children can develop water safety competency in short, intense learning blocks.
5. Distributed learning over longer periods would also add value to the education as weather patterns and water conditions fluctuate annually – which are not captured well in short-duration programmes.
6. Education providers that operate solely within swimming pools should consider opportunities to extend pool-based programmes to include exposure to open water environments. However, open water education should only be undertaken by trained and knowledgeable education providers: Local knowledge of the environment is crucial, as are appropriate supervision and risk management strategies.

## Conflict of Interest

The authors declare no conflict of interests.

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# Kinematic determinants of acceleration sprint performance in male academy Rugby Union players: Developing a technique model

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ABSTRACT

*The aim of this study was to identify which kinematic variables are associated with Rugby Union (RU) acceleration sprint performance (step velocity during the first three steps of a 40 m sprint) to create a technical model for RU acceleration sprinting. Nineteen semi-professional male academy RU players were split into fast (top quickest 40 m sprinters; n = 9, 5 backs and 4 forwards; age = 18.0 ± 0.5 years, height = 1.86 ± 0.07 m, mass = 88.9 ± 8.55 kg) and slow groups (bottom slowest 40m sprinters; n = 10, 2 forwards and 8 backs; age = 18.0 ± 0.5 years, height = 1.81 ± 0.07 m, mass = 91.6 ± 11.5 kg). Subjects completed 3 trials of a maximum effort 40 m sprint test. Step length, step duration, ground contact time, flight time, step frequency, step velocity, trunk angle at take-off, hip flexion angle at take-off, leg extension angle at take-off, shoulder extension angle at take-off, and touchdown distance were collected during the sprint via video analysis. After normality was inspected, intraclass correlation coefficients (ICC) and coefficients of variation (CV) were calculated to quantify movement variability and reliability. A series of Pearson's and Spearman's correlation analyses were conducted to identify which variables best correlated with step velocity. To explore differences between fast and slow groups, independent t-tests were performed with Hedges' g effect sizes calculated. ICCs and CVs for the combined groups displayed varied reliability and variability for all step characteristics (ICC = 0.511 to 0.920, moderate to excellent; CV = 4.50% to 20.8%). Correlations ranged from trivial to high where step length (r = 0.505, p = 0.028), trunk angle at take-off (r = -0.489, p = 0.034) step duration (r = -0.388, p = 0.100), step frequency (r = -0.344, p = 0.150), were the top four highest correlating variables to step velocity. Results of the current study suggest that these variables may predict successful RU sprint performance.*

## 1. Introduction

Rugby Union (RU) is a fast paced, high contact team sport (Baker, 1981) with two established groups of positions: forwards (*n* = 8; loose head prop, hooker, tighthead prop, 2 locks, blind side flanker, open side flanker, number 8) and backs (*n* = 7; scrum half, fly half, left wing, right wing, inside centre, outside centre, full back). Typically, forwards are bigger and heavier anthropometrically compared to backs, thus take a greater responsibility in the force and collision-based actions during the game. Contrastingly, backs hold a more athletic stature and are more responsible for the high-speed actions (Deutsch et al., 2007). However, whilst this is true, all RU positions still complete contact-based actions including rucks, mauls, and tackles, though due to differences mentioned, forwards exhibit a greater number of contacts compared to backs.

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Roberts et al. (2008) found forwards completed 35 ± 8 rucks compared to 11 ± 6 rucks in backs. In mauls, authors found forwards completed 25 ± 8 mauls vs 4 ± 4 in backs and for tackles, authors found forwards completed 14 ± 4 vs 10 ± 4 in backs. During match-play, RU players cover distances of approximately 8.5 km – 9.9 km (Cross et al., 2015; Lockie et al., 2013b) and also complete many dynamic actions across this distance of play, such as: set pieces, rucking, mauling, and change of direction but one of the most frequently performed actions in the game is sprinting (Deutsch et al., 2007). Players will usually sprint in bursts between 0 m – 40 m (Sayers, 2000) and have adopted a running technique, allowing them to reach speeds in excess of 90% of their maximum within this distance (Duthie et al., 2006), which is much earlier than track and field athletes, who typically reach speeds in excess of 90% of their maximum around 70 m – 80 m (Mackala & Mero, 2013).

Trunk angle at take-off, leg extension angle at take-off, step velocity (SV), step frequency (SF), ground contact time (GCT), flight time (FT), and step length (SL) are just some of the key components for acceleration in line with the deterministic model (Bezodis et al., 2019; Fletcher, 2009). These variables have been considered to be key due to the formula: Running speed = SF x SL (Bezodis, 2012). The deterministic model states that, a development in some of the key variables listed above can further improve components of this equation (Fletcher, 2009; Lockie et al., 2013b).

Biomechanically, acceleration is characterised by a 15° – 45° trunk lean with full triple extension of the rear leg (Bezodis et al., 2019; Kale & Acikada, 2016). This is desired in order to promote increased horizontal propulsive force and minimise braking, as increased trunk angles have been previously linked with larger propulsion forces (Kugler & Janshen, 2010). However, this may not be applicable for RU, due to differences in ecological constraints between track and field compared to RU. Within track and field, the use of a rubber track, starting blocks, and spiked running shoes, differs highly to that in RU. RU players complete sprints on grass/synthetic field-turfs and also have very different somatotypes (Wild et al., 2018).

In comparison to track and field, RU players have also been found to adopt a closed/hunched over running style with significant forward lean (Gambetta, 1996, 1997; Sheppard & Young, 2006). However, due to the constant visual scanning that occurs during RU, RU players' frequently change from a forward leant posture to a more upright running posture during gameplay in order to make correct decisions and respond appropriately to opponents. Therefore, whilst this adaptation may not be deemed the ideal way to accelerate according to track and field, RU players adapted running style has assisted them to suit the demands of the game and should not be discouraged (Gambetta, 1996, 1997). Nevertheless, it is still common for RU players to be coached in line with recommendations for track and field. Coaching RU players in this way is not tailored for the intercepting dynamic actions involved in RU, different running surfaces, different running postures, and also does not cater for the two different positional groups (Bradshaw et al., 2007; Ryan & Harrison, 2003).

As sprint acceleration is complex, and involves the rate of change in velocity, it places high physical demand on the performer and requires high levels of coordination to perform at superior standards (Young, 2007). The action is made up of an optimal combination of SF and SL. SF is defined as the rate at which footsteps can be repeated and SL is defined as the distance between alternating foot contacts (Hunter et al., 2004). Other factors involved in acceleration include GCT, which is the duration of the contact between the support leg and the ground, and FT, which is the period when the subject is airborne during the sprint step (Lockie et al., 2013a). Research has found that in order to improve SV and thus running speed, there must be an increase in one or both of SL or SF (Vittori, 1996) due to Running speed = SL × SF (Ryan & Harrison, 2003). However, research has paid particular attention to the importance of a higher SF for faster acceleration in team sports (Murphy et al., 2003; Sayers, 2000). Murphy et al. (2003) found that the players who could accelerate faster had a significantly higher horizontal hip velocity compared to the slower group which was due to the faster group having a 9% higher SF. The differences in SF were directly caused by the differences in GCT between the two groups (where faster players displayed shorter GCTs). Sayers (2000) also found similar, which could suggest shorter steps and thus shorter FTs could be beneficial for team sport sprint acceleration. Interestingly, some research has observed opposing findings, and shown SL to be the major contributor to acceleration (Bezodis et al., 2011; Lockie et al., 2013b; Nagahara et al., 2018) emphasising the complexity of the sprinting action. Lockie et al. (2013b) carried out a stepwise regression analysis and found large correlations between SV and SL between 0 m – 10 m ($r = 0.535$, $p = 0.016$). When GCT was added to the stepwise regression analysis for 0 – 10 m, the relationship was further strengthened ($r = 0.685$, $p = 0.006$). Similarly, Brughelli et al. (2011) found similar results, showing strong correlations between SV and stride length ($r = 0.66$, $p < 0.05$) in team sport players. Authors displayed a coefficient of variation (CV) of 9.6% for variables across the steps tested, showing findings to be reliable. However, Lockie et al. (2013b) failed to present CVs and also carried out testing procedures on an indoor basketball court whereas Brughelli et al. (2011) tested on a non-motorised treadmill. Therefore, whilst these findings are insightful, they are not ecologically valid as they eliminate the application for RU players who accelerate on grass and synthetic field-turfs. Despite this, Nagahara et al. (2018) supported that longer SLs correlate to higher sprinting speeds and found strong correlations between SL and sprinting speed across initial acceleration. But, whilst Nagahara et al's. (2018) correlations were low for SF, SF began to correlate stronger as the sprint progressed, suggesting that the variable SL may be more important for sprint acceleration, but SF may be an important factor for top end speed. However, whilst such findings are evident, it is clear much of the research has been conducted on mixed team sport samples and not solely RU. This is likely to cause a lack of transference to RU, implying further research is needed.

Unique to any other research, Wild et al. (2018) investigated step mechanics in RU players versus track and field athletes. Wild et al. (2018) found toe-off distance to be highest correlating variable to average normalised external sprint power where having a stance further behind the centre of mass at toe-off resulted in superior acceleration. Backs exhibited higher SVs displaying a more posterior touchdown distance compared to slower forwards. Morin et al. (2012) found smaller touchdown distances were related to a more forward orientated ground reaction force vector and thus smaller touchdown distances have been identified as a key determinant of acceleration. Wild et al. (2018) also found that touchdown distance for forwards relative to centre of mass was further forward compared to the fastest of all-time athletes, track, and field athletes, displaying a very large effect size (sprinters vs forwards). Differences in body masses between RU and track and field athletes are largely different. RU players are much heavier than track and field athletes, thus must produce larger external net forces in order to overcome their inertia which could suggest trunk angles may differ between RU and track and field athletes, also suggesting reason for differing TDs. However, further research is needed to prove this.

Previous research has identified an optimal sprint technique for the most efficient acceleration and maximal speed; however, applying such recommendations does not cater for the intercepting demands involved in RU, leaving players exposed to potential injury. Therefore, the aim of this study is to identify which kinematic variables are associated with RU acceleration sprint performance (SV during the first three steps of a 40 m sprint) to in turn create a technical model for initial acceleration in RU. In addition, differences between faster and slower players will be explored. It was hypothesised that: (a) the faster group would display significantly faster SVs compared to the slow group, where the fast group would have a combination of both a higher SL and SF compared to the slow group; (b) ≥ large correlation would be exhibited between SVs and SF where the faster group would exhibit a significantly faster SFs than the slow group; and (c) SV and FT would display a ≥ large correlation where the fast group would also display shorter FTs compared to the slow group.

## 2. Methods

### 2.1. Participants

Based on previously published methods (Calderbank et al., 2021), nineteen semi-professional elite male academy RU players were recruited to partake in the study. Subjects were split into fast and slow groups where the top nine quickest 40 m sprinters (time to completion) were deemed to be in the fast group (*n* = 9, 5 backs and 4 forwards; age = 18.0 ± 0.5 years, height = 1.86 ± 0.07 m, mass = 88.9 ± 8.55 kg) and the bottom ten slowest 40 m sprinters (time to completion) were deemed to be in the slow group (*n* = 10, 2 forwards and 8 backs; age = 18.0 ± 0.5 years, height = 1.81 ± 0.07 m, mass = 91.6 ± 11.5 kg). Using a power of 0.8, and type 1 error or alpha level of 0.05, a minimum of 14 (*n* = 7 each group) subjects was determined from an *a priori* power analysis using G*Power (Version 3.1.9.2, University of Dusseldorf, Germany) based upon a previously established Cohen's *d* effect size of 1.69 for contact time during the first three steps (steps 1 – 3) (Wild et al., 2018; Dos'Santos et al., 2020). For the testing procedures, all subjects were highly familiar with testing and training procedures for sprinting and strength & conditioning. Subjects wore studded rugby boots for sprinting trials and were also injury free. Ethical approval was obtained from the University of Salford ethics board. Written informed consent along with a physical activity readiness questionnaire were provided to all participants for completion prior to data collection to check eligibility for study participation. Previous research into time-motion during field-based team sports, has shown that during competition, 40 m is the maximum distance likely to be sprinted in one burst by RU players, although on average sprints tend to range between 0 – 20 m therefore step mechanics will be taken during the 0 – 20 m portion of the sprint (during the first three steps of the sprint) (Spencer et al., 2005).

### 2.2. Apparatus and task

In line with Calderbank et al. (2021) testing was carried out in one testing session. The 40 m sprint test was selected as 40 m is the maximum distance likely to be covered through a sprint burst during a RU game (Sayers, 2000). Additionally, as the RU players in this study complete 40 m sprints regularly as part of their training, it also allowed for training consistency to be held. The test has also been shown to be highly reliable (Darrall-Jones et al., 2016). Three maximal effort trials were completed by each subject on a synthetic 3G AstroTurf surface. Similar to previous research, a video camera was placed between the 0 – 10 m portion of the track in order to evaluate step mechanics (Wild et al., 2018; Calderbank et al., 2021). Video acquisition of kinematics can be seen in Table 1. Intraclass correlation coefficients (ICCs) with 95% confidence intervals (CI) and CVs were calculated for the fast and slow groups combined, for the fast group independently, and for the slow group independently. Group comparisons were made for all step mechanic variables and Hedges' *g* effect sizes calculated.

Table 1: Acquisition/definition of step mechanic variables (Hunter et al., 2004; Seagrave et al., 2009).

| **Step Mechanics** | **Process of Acquisition/Definition** |
|---|---|
| Step length (m) | Toe to toe horizontal distance between consecutive foot contacts. |
| Step duration (s) | Number of frames from take-off to take-off of consecutive steps × 1/100 |
| Ground contact time (s) | Number of frames from touchdown to take-off of one-foot contact × 1/100 |
| Flight time (s) | Number of frames from take-off to touchdown, during one step × 1/100 |
| Step frequency (Hz) | 1/ step duration |
| Step velocity (m/s) | Step length × step frequency |
| Trunk angle at take-off (°) | Angle of trunk relative to the vertical at take-off. Where a lower trunk angle would be a more upright and vertical posture. |
| Leg extension angle at take-off (°) | Angle of rear leg (ankle to hip) at full extension relative to vertical at take-off (A lower angle would indicate less leg extension at take-off). |
| Hip flexion angle at take-off (°) | Angle of thigh of forward leg (centre of knee to hip) relative to horizontal at take-off. A lower hip flexion angle would have greater knee lift. |
| Shoulder extension angle at take-off (°) | Angle formed between upper arm and trunk at take-off. Where a greater shoulder extension angle would result in a greater backward arm drive. |
| Touchdown distance (m) | Horizontal distance of toe to hip at touchdown. A foot landing further forwards relative to the hip would result in a greater touchdown distance. |

### *2.3. Procedure*

The data collection used an experimental quantitative approach (between subjects, cross sectional design). The study assessed the variables listed and defined in Table 1 during the first three steps of the 40 m sprint. The study used similar methods to Calderbank et al. (2021) and are summarized here.

Subjects undertook a standardized warm up in line with previous successful research (Dos'Santos et al., 2017). The 40 m track was marked out on the testing surface. The camera set up can be seen in Figure 1. Placed on a rigid tripod 0.98 m off the floor, the Panasonic Lumix DMC - FZ200 camera (Panasonic corporation, Kadoma, OSA, JP) sampled at 100 Hz with a resolution of 1280 x 720p was set on a manual focus. The camera set up permitted evaluation of the first three steps of each trial. As positioned in Figure 1, one pair of Draper flood lights (WL28, Draper, UT, USA) (1500 watts) were set on a 3 m tall tripod. Although the camera field of view was 7 m, measurements were only taken in the central 5 m to reduce parallax error. Prior to data collection, in the centre of the track, a 1.22 m calibration frame was taken directly in front of the camera frame.

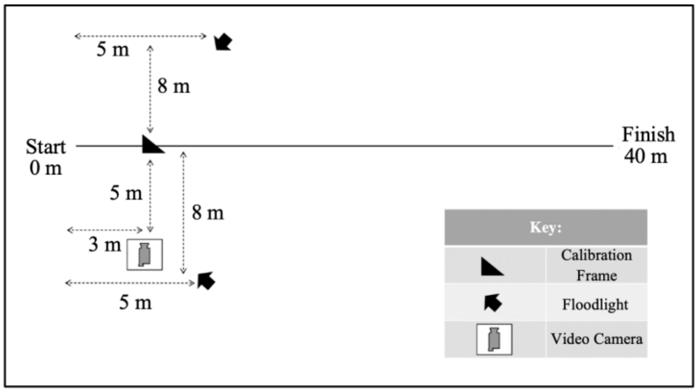

Figure 1: Diagram of 40 m sprint test set up.

Upon starting each trial, subjects were informed to start 0.5 m behind the start line in a 2-point athletic start before then completing three maximal 40 m sprint efforts each with a 3- to 4-minute rest period between (Wild et al., 2018). Subjects started each effort with the synchronization of the camera recording for each trial and were instructed to *run as fast as possible and to not decelerate until they passed the finish line* and were given encouragement throughout (Woolford et al., 2013). A step was defined as one consecutive movement of right foot contact to left foot contact (Wild et al., 2018; Calderbank et al., 2021). The point of touchdown was identified as the first frame the foot was visibly in contact with the ground and toe-off was identified as the first frame the foot had visibly left the ground (Wild et al., 2018; Calderbank et al., 2021).

Videos were imported and calibrated using into the computer system and analysed using Quintic Biomechanics software (Version 31, Solihull, UK). Through this software the 'angle drawing', 'shapes', and 'marker' functions were utilised to determine all step mechanic variables (Table 1) during the first three steps (these values were then averaged across steps then reported). The data was then separated into groups: groups combined, fast group, and slow group.

### *2.4. Statistical approach*

Using ICC (ICC 3,1) with 95% CI (Shrout & Fleiss, 1979; Wild et al., 2018), test-retest intra-rater reliability of manual digitization for all step mechanics was determined. Similar to Wild et al. (2018) and Calderbank et al. (2021), the data of 10 subjects, was selected at random from the sample and digitized on two separate occasions (2 weeks apart). Using SPSS for Mac (Version 27; SPSS Inc., Chicago, IL, USA) ICCs, CVs, and CIs were calculated. ICCs with 95% CI were determined to test rank order consistency between trials (two-way mixed effects, average measures absolute agreement) for the groups when combined, and separately. Using the Koo and Li (2016) scale, ICCs were interpreted as poor reliability (< 0.5), moderate reliability (0.5 – 0.75), good reliability (0.76 – 0.9), and excellent reliability (> 0.9), where ICC ≥ 0.7 was deemed acceptable (Baumgartner & Chung, 2001). Intra-rater reliability with 95% CI was calculated (two-way random effects, average measures, absolute agreement). For each variable, using the formula: standard deviation divided by the mean multiplied by 100, percentage within subject CV was calculated to determine the variability across the three trials. Ninety-five percent CIs for CVs were calculated and reported. An acceptable CV was < 15% (Baumgartner & Chung, 2001). Using a Shapiro-Wilks test normality was inspected. Normality ($p > 0.05$) was established for all variables highlighted in Table 1. To explore differences between fast vs slow groups for variables established as normal a parametric independent samples t-test was used. A Levene's test was used to test the assumption of equality of variances, with degrees of freedom adjusted for 'variances not assumed' for violations of this assumption. Step duration and FT and SV were not normally distributed ($p < 0.05$). In order to explore differences between fast and slow groups for variables not normally distributed, a Mann-Whitney U test was used. To explore the relationship between step mechanics and SV a series of parametric Pearson's correlations were conducted with significance set to $p \leq 0.0045$, Bonferroni adjusted to allow for multiple correlations. However, as step duration and FT were not normally distributed, a series of non-parametric Spearman's rank correlations were conducted for these variables. In agreement with Hopkins (2002) correlation values were interpreted as less than trivial (≤ 0.1), small (0.11 – 0.3), moderate (0.31 – 0.5), large (0.51 – 0.7), very large (0.71 – 0.9), and almost perfect (0.91 – 1.0). The data was split into fast and slow groups where the top nine subjects with the fastest SV were deemed 'fast' and the bottom ten subjects with the slowest SV were deemed 'slow'. Effect sizes were determined and corrected using Hedges' *g* due to uneven sample sizes, with values interpreted as follows: trivial (≤ 0.19), small (0.20 – 0.59), moderate (0.60 – 1.19), large (1.20 – 1.99), very large (2.0 – 4.0), and extremely large (≥ 4.0) (Hopkins, 2002).

## 3. Results

Excellent intra-rater reliability (between first and second digitization) was found for all step characteristics (ICC = 0.993 to 1.00, 95% CI = 0.972 to 1.00). Mixed reliability and variability (ICC = 0.511 to 0.920, moderate-excellent; CV = 4.50% to 20.8%) was found for all step characteristics in grouped data (Figure 2).

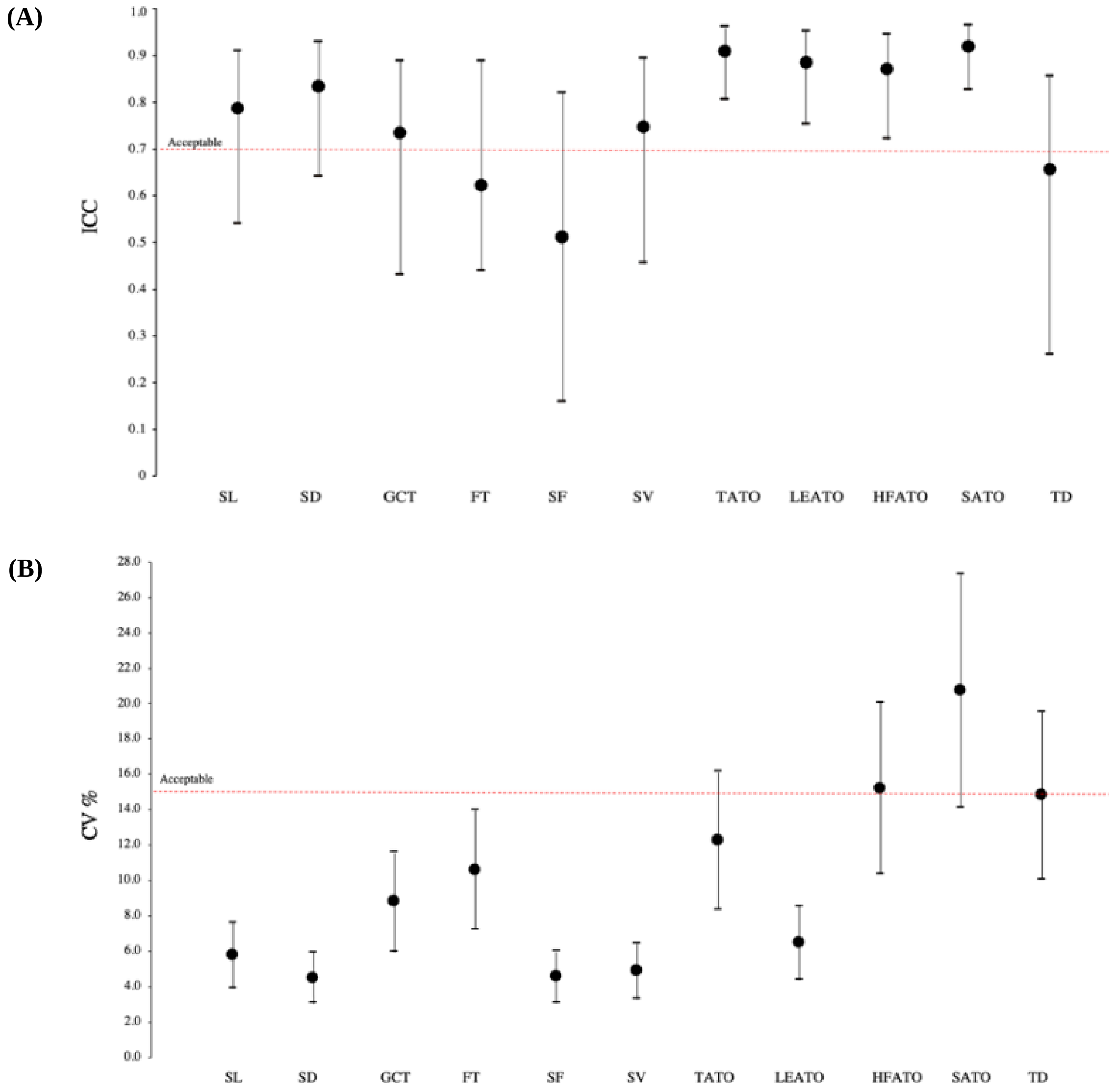

Figure 2: (A) Reliability (ICC) and (B) variability (CV) measures for step mechanics variables (groups combined). Error bars represent upper and lower 95% confidence intervals.

For fast and slow groups, step mechanics demonstrated varied results (fast ICC = 0.519 to 0.955; slow ICC = 0.202 to 0.832; fast CV = 2.57% to 15.57%; slow CV = 0.97% to 16.09%). Effect sizes ranged from trivial to large (*g* = 0.00 to -1.456) and correlations ranged between trivial to high (*r* = -0.009 to 0.505) (Table 2 and Figure 3).

## 4. Discussion

The study aimed to identify which kinematic variables were associated with RU sprint performance (SV during the first three steps) and to explore differences between faster and slower players to in turn create a technical model for initial acceleration in RU. The faster group displayed significantly faster SVs, with both higher SF and SL compared to the slow group, accepting the hypothesis. SV- SF displayed a moderate correlation (*r* = -0.344, *p* = 0.150) and SV- SL displayed a high correlation, (*r* = 0.505, *p* = 0.028), thus partially accepting the hypothesis. The fast group displayed identical FTs compared to the slow group, where SV-FT displayed only a small correlation (*r* = -0.191, *p* = 0.434), rejecting the hypothesis.

SL results from the current study displayed highest correlations with SV in a positive direction. SV is the product of SL and SF (SV = SL x SF) where, step duration is also directly influenced by the combination of SL and SF and thus SV. In the current study, step duration and SF displayed a moderate correlation and moderate effect size. Whereas, although SL displayed the highest correlation in the current study, SL displayed only a small effect size. Therefore, suggesting both fast and slow RU players can produce similar SLs meaning the discrepancy between fast and slow SVs is likely due to SF. Findings by Murphey et al. (2003) agreed with findings of the current study.

Table 2: Descriptive statistics and effect sizes of step mechanics variables and correlation coefficients of step mechanics variables with step velocity.

| | **Groups Combined** | | | **Fast Group** | **Slow Group** | | |
|---|---|---|---|---|---|---|---|
| **Step Characteristics** | **Mean ± SD** | ***r*** | ***p*** | **Mean ± SD** | **Mean ± SD** | ***g*** | ***p* (2-tailed)** |
| Step length (m) | 1.27 ± 0.13 | 0.505$^{a}$ | 0.028 | 1.27 ± 0.07 | 1.25 ± 0.06 | 0.286$^{c}$ | 0.116 |
| Step duration (s) | 0.24 ± 0.01 | -0.388$^{b}$ | 0.100# | 0.23 ± 0.01 | 0.24 ± 0.01 | -0.952$^{b}$ | 0.094† |
| Ground contact time (s) | 0.14 ± 0.01 | -0.180$^{c}$ | 0.460 | 0.14 ± 0.11 | 0.15 ± 0.12 | -0.082$^{d}$ | 0.224 |
| Flight time (s) | 0.09 ± 0.01 | -0.191$^{c}$ | 0.434# | 0.09 ± 0.01 | 0.09 ± 0.01 | 0.00$^{d}$ | 0.632† |
| Step frequency (Hz) | 4.25 ± 0.20 | -0.344$^{b}$ | 0.150 | 4.30 ± 0.17 | 4.21 ± 0.17 | 1.008$^{b}$ | 0.059 |
| Step velocity (m/s) | 5.36 ± 0.26 | | | 5.48 ± 0.23 | 5.25 ± 0.13 | 1.173$^{b}$ | < 0.001† |
| Trunk angle at take-off (°) | 34 ± 4.00 | -0.489$^{b}$ | 0.034 | 32 ± 1.00 | 36 ± 4.00 | -1.456$^{a}$ | 0.107 |
| Leg extension angle at take-off (°) | 43 ± 3.00 | 0.320$^{b}$ | 0.182 | 44 ± 2.00 | 43 ± 3.00 | 0.584$^{c}$ | 0.691 |
| Hip flexion angle at take-off (°) | 29 ± 5.00 | -0.321$^{b}$ | 0.180 | 28 ± 4.00 | 30 ± 5.00 | -0.368$^{c}$ | 0.370 |
| Shoulder extension angle at take-off (°) | 49 ± 10.0 | -0.009$^{d}$ | 0.969 | 48 ± 6.00 | 50 ± 13.0 | -0.124$^{d}$ | 0.543 |
| Touch down distance (m) | 0.26 ± 0.04 | -0.013$^{d}$ | 0.956 | 0.25 ± 0.32 | 0.26 ± 0.03 | -0.042$^{d}$ | 0.639 |

*Note:* Interpretations for *r* and *g* values: $^{a}$high/large; $^{b}$moderate; $^{c}$small; $^{d}$trivial. SD = standard deviation; *g* = Hedges' *g*; #Spearman's correlation; †Mann-Whitney U.

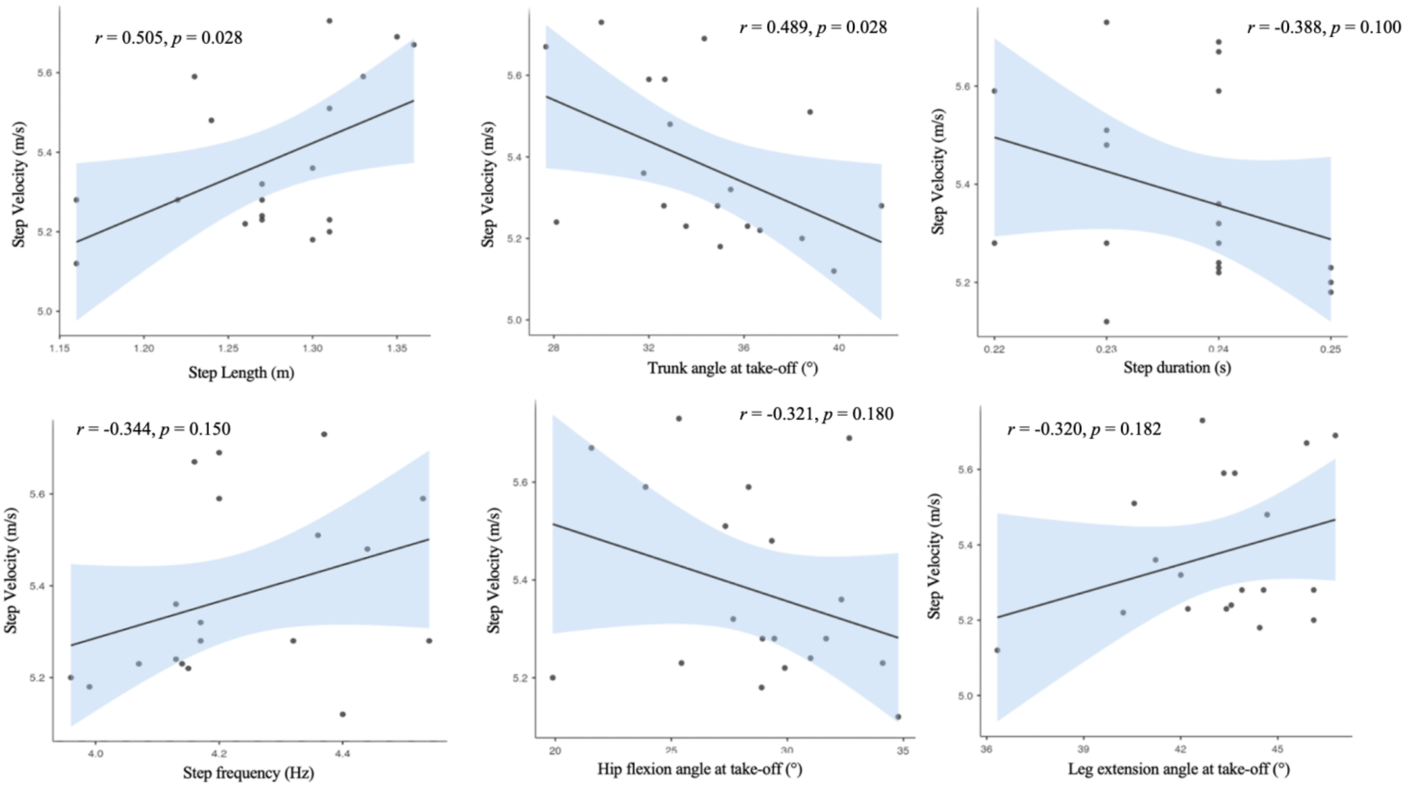

Figure 3: Scatter Plots and 95% confidence intervals displaying relationship between step velocity and the six highest correlating step mechanics; step length, trunk angle at take-off, step duration, step frequency, hip flexion angle at take-off, and leg extension angle at take-off.

Murphey et al. (2003) found that subjects with a higher acceleration had a 9% higher SF compared to the slower group. They concluded that the reason their athletes were able to generate higher SVs over short distances was due to reduced GCT, contrasting results from the current study. GCT results from the current study displayed both a small correlation and small effect size. Both fast and slow groups in the current study failed to produce differences, which may be due to the relatively similar body masses between the two groups explained by impulse-momentum relationship ($F_{mean} \times \Delta t \propto p = mv - mv_0$; $F_{mean}$ = mean force, $\Delta t$ = change in time, $p$ = momentum, $m$ = mass, $v$ = final velocity, $v_0$ = initial velocity). In the current study, two thirds of sample were forwards who had a larger body mass compared to that of lighter backs. Therefore, heavier forwards are more likely to have larger GCTs, as they aim to maximize force production, resulting in longer force application (longer GCTs), thus making them more SL dependent and less SF dependent. Which could imply, RU sprinting success relies on the ability for one to reach the highest possible SF (whilst maintaining the longest possible SL).

Trunk angle at take-off displayed a moderate correlation with SV, exhibiting a large effect size. Whilst players presented some forward lean, trunk angle at take-off results suggest that a more upright torso angle (smaller torso angle) is advantageous (similar to trunk angle at take-off in the maximal speed phase of the technical model) (Ryan & Harrison, 2003), where large differences were displayed between the fast and slow groups ($g$ = -1.456).

It is likely that RU players in the current study adopted an upright position due to players being accustomed to the constant visual scanning that occurs during RU match-play (Meir, 2005) commonly practiced during many RU training drills (Sayers, 2000). It is important for RU players to sprint with an upright position in order to assess the game and make correct decisions for successful performance. In contrast La Monica et al. (2016) and Sayers (2000) found that adopting an upright posture during certain game-time scenarios, could potentially leave players exposed to injury as this may leave players in a more open unprotected position. Thus, more vulnerable to contact collisions. Though this is clear, the 40 m sprint test used in the current study does not show a true representation of actual RU match-time sprint performance. The 40 m sprint test does not include intercepting contact collisions between sprint bursts that occur during live match-play. Practitioners should consider analyzing sprint mechanics live during match-play to gain an even better understanding of their athlete's sprint performance.

Hewit et al. (2013) used similar methods to the current study although found opposite. Hewit et al. (2013) found significant differences between fast and slow groups where faster players exhibited a larger trunk angle at take-off. The differences exhibited between the current study and findings found by Hewit et al. (2013) may also be due to anthropometrics. Although researchers used a team sport subject sample, players were not RU based were of a similar body mass to the average body mass of track and field athletes. Therefore, direct between study comparisons cannot be made. In the current study, correlations between hip flexion angle at take-off and SV, and Leg extension angle at take-off and SV displayed moderate correlations. Results suggest that a higher knee lift combined with that of a greater leg extension angle is beneficial for RU sprint performance. These findings agree with the current technical model (Ryan & Harrison, 2003). Wild et al. (2018) found faster backs had a more posterior touchdown and toe-off position, thus displaying greater Leg extension angle at take-off. This enabled backs to maximize propulsion and limit braking compared to that of slower forwards, suggesting this is likely the case in the current study.

Shoulder extension angle at take-off and touchdown distance in the current study presents trivial findings. Previous studies suggest that a bigger arm drive enables players to exhibit enhanced sprint performance combined with that of a shorter touchdown distance (Macadam et al., 2018). Though this agrees with results of the current study, results were trivial. Previous research found that not only does the arm action counterbalance the rotary momentum of the legs during sprinting, but a larger arm drive also plays an important role during early acceleration by contributing to up to 10% of the total vertical propulsive force the body can apply to the ground (Macadam et al., 2018). However, though this is true, results from the current study suggest that shoulder extension angle at take-off and touchdown distance do not determine sprint performance.

In conclusion, Figure 4 displays the new technical model for RU sprint acceleration performance. Results of the current study suggest that the driver for superior sprint performance is due to one's ability to maximize SF (minimize step duration) whilst maintaining the longest possible SL with a more upright torso. To further enhance results, a more extended leg at take-off with combined greater knee lift should be adhered to. Therefore, it can be seen in Figure 4, if the variables shaded in turquoise and yellow are improved, more successful RU sprint performance may be exhibited. Results suggest that, in order to fine tune performance, a quicker GCT, shorter FT, a greater shoulder extension angle at take-off and shorter touchdown distance should be adhered to in order to maximize propulsion, limit braking and thus exhibit faster sprint times.

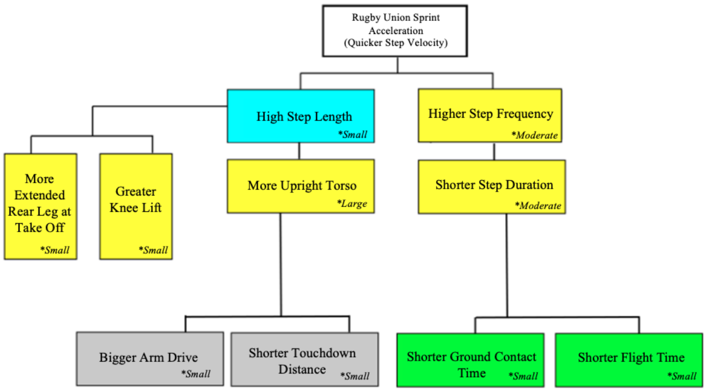

Figure 4: Rugby Union Sprinting Technical Model for Acceleration. Turquoise represents strongest correlating variables to acceleration performance followed by yellow, green, and then grey. *Hedges' $g$ effect size.

## Conflict of Interest

The authors declare no conflict of interests.

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# Assessing the Omega-3 Index of a professional cycling team and the influence of ad libitum provision of fish oil during the competitive season

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ABSTRACT

*An optimal omega-3 status, which is modified by increased consumption of long chain omega-3 eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), supports cardiovascular and anti-inflammatory physiology. This study described the omega-3 status of riders in a professional cycling team and following ad libitum provision of a fish oil supplement over the course of a competitive season. The omega-3 status of professional riders ($n = 23$) was assessed via measurement of the Omega-3 Index (O3I), the omega-6/omega-3 (n-6/n-3), and Arachidonic Acid/EPA ratio (AA/EPA) using a finger prick blood sample at the start of the season. A quasi-experimental design provided riders ad libitum access to a fish oil supplement (NAMEDSport, Italy) with advice to consume two capsules per day (1,118 mg EPA + 458 mg DHA). Follow up blood samples were collected ($n = 13$) at the end of the season (16 – 18 weeks) and expressed according to self-reported achievement of the advised dose. At pre-season, five of the riders returned an O3I > 8% (mean = 7.07%, 95% CI [6.51, 7.63]). The mean n-6/n-3 ratio was greater than 5 (mean = 5.38, 95% CI [4.81, 5.96]), and the AA/EPA was less than 11 (mean = 8.41, 95% CI [6.35, 10.47]). By the end of the season, seven riders self-reported meeting the daily dose recommendations and increased their O3I (pre-season mean = 6.81%, SD = 1.97; post-season mean = 9.06%, SD = 1.06, $p < 0.01$, Bonferroni adjusted), compared to six riders who reported sub-optimal (inconsistent) intake and the O3I remained unchanged (pre-season mean = 7.11%, SD = 0.75; post-season mean = 7.09%, SD = 0.47, $p = 0.97$, Bonferroni adjusted). Optimising the omega-3 status of elite cyclists is possible when ad libitum provision of supplemental fish oil enables daily achievement of EPA + DHA intake. Riders consistently consuming two capsules per day elevated and/or maintained optimal omega-3 status alongside the arduous nature of training and competition.*

## 1. Introduction

The physiological demands of professional road cycling require a rider to withstand significant physiological stress (Novak & Dascombe, 2014). Performance nutrition primarily and rightly focusses on carbohydrate and protein intake to enhance physiological and performance outcomes (Burke, 2001). Notwithstanding, the profile of dietary fat including the proportions of saturated, monounsaturated, and polyunsaturated fatty acids is complex and extends beyond simplistic provision of energy. In fact, long chain omega-3 polyunsaturated fatty acids (LCn-3PUFA) have differential impacts for modifying cell membranes of tissues, such as skeletal (Andersson et al., 2002)

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and cardiac muscle (Metcalf et al., 2007) that includes physiological adaptation to both organs (Helge et al., 2001; McLennan 2014). This has resulted in growing interest about LCn-3PUFA intake in athletic populations, and especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) according to dose and duration (Lewis et al., 2020; Murphy & McGlory, 2021).

It is well-established that regular dietary consumption of fish oil leads to the preferential incorporation of EPA + DHA into cardiac and skeletal muscle membrane phospholipids, via replacing omega-6 arachidonic acid (AA), in a dose-related manner (Slee et al., 2010), and according to muscle fibre type (Macartney et al., 2019). Erythrocyte membrane LCn-3PUFA composition correlates closely with human muscle (Harris et al., 2004), has a low biological variability (Harris & Thomas, 2010), and is easy to obtain which makes it the preferred biomarker for confirming incorporation of EPA + DHA into tissue. Several assessments of erythrocyte membrane LCn-3PUFA composition can be made including the well-established Omega-3 Index (O3I: %EPA + DHA) with an optimal target > 8% for heart function (Harris & Von Schacky, 2004). Additionally, the ability of the endurance cyclist to obtain a whole blood AA/EPA ratio < 11 and omega-6/omega-3 (n-6/n-3) ratio < 5, for enhanced anti-inflammatory pathways and pro-resolution actions, has been recently reported as a case study whilst competing at the Tour de France (Macartney et al., 2021a). Collectively, these measures of LCn-3PUFA composition will be referred to as ‘omega-3 status’ from this point forward.

Notwithstanding, there are currently few translational studies in elite endurance athletes taking part in training and seasonal competition. Furthermore, overall study design including omega-3 dose, have incurred some limitations. For example, pharmacological doses of omega-3 fatty acids (> 3500 mg per day which would require an individual to consume approximately 10 typical 330 mg EPA + DHA capsules per day) in elite swimmers (Mickleborough et al., 2003) and paddlers (Delfan et al., 2015) and over short time periods of 3 – 4 weeks respectively or up to 7 weeks in marathon runners (Santos et al., 2013) prevent long term evaluation over a season or more. Dose and time considerations are critical as highly controlled laboratory animal studies demonstrate that a minimum target of 600 – 800 mg of EPA + DHA per day via fish oil optimises skeletal muscle according to fibre type (Macartney et al., 2019) and cardiac membrane concentrations (Slee et al., 2010). This same dose of DHA-rich oil is reflected by improvements in red blood cell membranes over the course of 8 weeks in trained individuals (Hingley et al., 2017). However, it remains to be established, using the biological marker of the erythrocyte membrane, whether *ad libitum* provisions of an evidence-based dose of EPA + DHA is sufficient to maintain optimal omega-3 status in elite endurance riders where protracted physiological stress and fatigue are dominating.

In summary, professional cycling teams are not necessarily aware of the impact of an elite rider’s usual dietary fatty acid intake on the omega-3 status of their tissues nor the biological relevance of these fatty acids. Moreover, athletes are scarcely provided advice for LCn-3PUFA intake via supplemental source, and definitely not informed from blood biomarker sampling such as the O3I while simultaneously training and competing. Therefore, this quasi-experimental and translational study aimed to i) evaluate the fatty acid profile of an elite UCI cycling team at the commencement of the season and ii) provide feedback and LCn-3PUFA supplementation advice from these pre-season results in the aim of achieving and maintaining optimal omega-3 status (O3I > 8%; n-6/n-3 < 5; AA/EPA < 11) across the professional season. We hypothesised that a targeted and evidenced-based LCn-3PUFA evaluation and advice program whereby riders received ad libitum access to an EPA + DHA fish oil supplement, alongside usual performance nutrition goals, would optimise and maintain their omega-3 status.

## 2. Methods

### 2.1. Participants and ethical approval

Each participant was a professional rider (European), contracted to the same Union Cycliste Internationale registered cycling team, at the time of the study (season 2020). Each rider (*n* = 23; age = 29 ± 4 years; height = 180 ± 7 cm; body mass = 67 ± 5 kg) took part in a minimum of one grand tour during the course of the study. The study procedures were approved by the University of Wollongong Human Research ethics committee (UOW HE-40421), each participant provided their informed consent and the study was conducted in accordance with the Declaration of Helsinki.

### 2.2. Study design

This quasi-experimental study was completed during the cycling calendar (2020) in the lead up to and including the three grand tours, described in the previous case study (Macartney et al., 2021a). That season, the European professional cycling races were delayed due to COVID-19 restrictions, and therefore the time points described are in line with the alterations to the professional cycling calendar. The months of July and August were dedicated to early season races leading into the first of these grand tours (Tour de France, France) and extended into October and November (Giro, Italy and Vuelta, Spain). The whole-blood fatty acid profile of each rider (*n* = 23) was objectively measured in the first week of July (pre-grand tours) and then during the period October to November (post-grand tours) where riders were still available and still competing (*n* = 13). During the season, the riders were provided with *ad libitum* access to an omega-3 fish oil supplement and were provided advice to achieve optimal omega-3 status as reflected by red blood cell membrane changes. Riders were asked to self-report supplement intake to the team’s medical staff according to their success (‘yes’ or ‘no’) in achieving the recommendations (daily consumption of the dose). Accordingly, riders were then divided at the end of the season into two groups, either not meeting (Sub-optimal, *n* = 6) or consistently meeting (Optimal, *n* = 7) the daily targets for omega-3 fish oil capsule intake. This process of allocation to groups was completed before the whole blood samples were analysed for relative membrane fatty acids content.

### 2.3. Whole blood fatty acid profile

At the start and the end of the season, each rider provided a morning fasted and adequately hydrated, blood sample using the finger prick method. The blood was collected according to best practice guidelines (Omega-Quant, South Dakota, United States) which included maintaining the erythrocyte membrane (no lysis) and relative plasma volume. That is, very gently and without squeezing the finger, the drop of blood was spotted onto the commercially available collection card for independent analysis (Omega-Quant, South Dakota, United States). The sample card was immediately sent to Omega-Quant (USA) to determine the whole-blood fatty acid profile using state of the art gas chromatography. Each fatty acid in the whole blood was individually identified using high quality standards and then described as a relative percentage (%) of all the fatty acids. The red blood cell O3I, a marker of cardiac and skeletal muscle membrane incorporation, was then calculated according to a validated algorithm ($r = 0.96$) (Harris & Polreis, 2016).

### *2.4. Description of nutritional objectives*

During the season, the cyclists followed the nutritional guidelines given by the nutritionist (MH). The nutrition plan was adjusted to the training program and took into account the personal nutrition goals and team goals for the race season. The team objective during the races was to support the performance and recovery between the stages. During the grand tours, the team consumed personalized meals which were calculated by the nutritionist, taking into account the total energy requirements and macronutrient composition. Fish (100 – 150 g serving) was included as part of the diet 1 – 2 times per week. On race days riders consumed a carbohydrate rich menu, consisting of five meals (breakfast, post-race, arrival at hotel, dinner and pre-sleep), prepared by the team chef. For each stage, the riders received a nutrition plan that was adjusted to the difficulty of the stages.

### *2.5. Fish oil supplement*

All the riders had access to the approved anti-doping omega-3 supplement (NAMEDSport, Italy) which was supplied by their professional team. The Omega-3 Double Plus Soft Gels (1 g each) contained concentrated fish oil and tocopherol-rich extract (antioxidant), for the stability of the fatty acids, in a gelatine capsule (soft gel). Each capsule of LCn-3PUFA rich fish oil contained EPA (559 mg) and DHA (229 mg). To achieve an optimal omega-3 status as rapidly as possible and before the scheduled start of the first grand tour, riders were advised to consume two capsules (NAMEDSport, Italy) each day, providing a total of 1,118 mg of EPA + 458 mg of DHA. This recommendation was employed to be sure that the minimum recommended intake of 600 – 800 mg EPA + DHA was achieved and exceeded by the *ad libitum* provision. Most importantly, the two capsules were consumed with food as part of breakfast and continued through the duration of season in the aim of establishing an O3I > 8%. During the grand tours, riders were reminded face to face about the daily consumption. In the times between the grand tours, the riders were provided the advice, but it was up to the individual to make use of the *ad libitum* supply. At the end of the season, and at the time of the second blood sample, the riders who were re-sampled ($n = 13$) were then asked to report about their intake on the basis of consistently meeting the recommendations of two capsules per day or not (‘yes’ or ‘no’).

### *2.6. Statistics*

Collected data was analysed using GraphPad Prism 9 (GraphPad Software, San Diego, CA, USA) software package. Baseline (pre-tours) blood samples ($n = 23$) were analysed using descriptive statistics. Follow up blood samples collected ($n = 13$) at the end of the season (post-tours) were grouped according to self-reported achievement of the advised dose (Sub-optimal or Optimal). Data were analysed using a repeated measures two-way ANOVA with factors of supplement group (Sub-optimal, $n = 6$; Optimal, $n = 7$) and time (pre, post). When a significant interaction or main effect was detected, *post-hoc* multiple comparisons were completed and the $p$-value was adjusted using the Bonferroni procedure. The distribution of continuous data was analysed for normality using the D’Agostino-Pearson omnibus (K2) test and homogeneity of variances was confirmed via Brown-Forsythe test. The data collected was expressed as mean (standard deviation or 95% CI) where appropriate. Alpha was set at $p < 0.05$.

## 3. Results

### *3.1. Omega-3 status in the cohort*

The usual intake of dietary fatty acids, including the LCn-3PUFA, in a cohort of elite professional cyclists revealed only 22% (5 out of 23) of the riders had an O3I above 8% (mean = 7.07%, 95% CI [6.51, 7.63]; Figure 1A). The mean sum of n-6 PUFA comprised of one third of the relative proportion where AA contributed close to 9% on average (Table 1). The mean n-6/n-3 ratio was greater than 5 (mean = 5.38, 95% CI [4.81, 5.96]; Figure 1B) nonetheless, the mean AA/EPA ratio was less than 11 (mean = 8.41, 95% CI [6.35, 10.47]; Figure 1B) although several riders were > 11 and the maximum was 21.0 in one athlete.

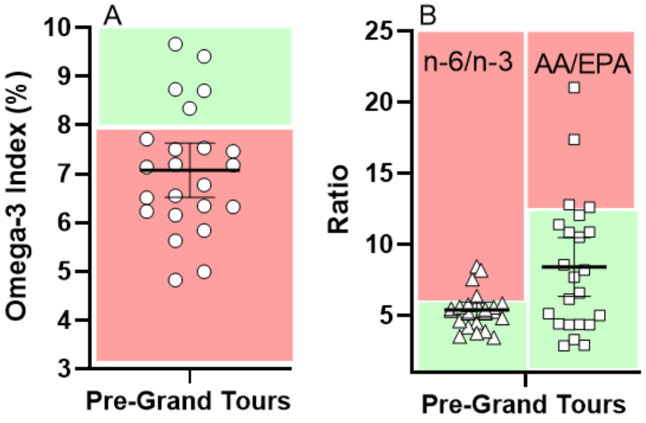

Figure 1: (A) Red blood cell Omega-3 Index (%EPA + DHA) and (B) Whole blood relative fatty acid ratios (%) of n-6/n-3 and AA/EPA of professional team riders ($n = 23$) before the Grand Tours (pre-season). Green = Optimal zone and pink = Sub-optimal zone for each parameter. Data expressed as mean (± 95% CI) along with individual scatter plot. Abbreviations: n-6/n-3, omega-6 to omega-3 ratio; AA/EPA, Arachidonic acid to Eicosapentaenoic acid ratio.

Table 1: Whole blood relative fatty acid profile (%) and red blood cell Omega-3 status in professional team riders before the Grand Tours (pre-season).

| Fatty acid | Mean (%) | SD | Min (%) | Max (%) |
|---|---|---|---|---|
| Σ SFA | 36.1 | 1.98 | 32.70 | 39.60 |
| Σ MUFA | 22.7 | 1.90 | 19.0 | 26.80 |
| Σ PUFA | 41.2 | 2.30 | 36.90 | 46.20 |
| LA | 22.5 | 2.50 | 17.90 | 26.80 |
| AA | 8.94 | 1.25 | 6.96 | 11.60 |
| Σ n-6 PUFA | 34.5 | 2.38 | 31.1 | 39.4 |
| ALA | 0.30 | 0.10 | 0.18 | 0.48 |
| EPA | 1.36 | 0.62 | 0.43 | 2.72 |
| DHA | 3.69 | 0.63 | 2.32 | 5.52 |
| Σ n-3 PUFA | 6.71 | 1.38 | 4.33 | 9.34 |
| n-6/n-3 | 5.38 | 1.33 | 3.44 | 8.45 |
| AA/EPA | 8.41 | 4.76 | 2.87 | 21.0 |
| O3I | 7.07 | 1.29 | 4.82 | 9.66 |

*Note:* Data collected from professional team riders ($n$ = 23) are expressed as mean and standard deviations unless otherwise noted. Abbreviations: SD, standard deviation; Min, minimum; Max, maximum; SFA, Saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA polyunsaturated fatty acids; LA, Linoleic Acid; AA, Arachidonic Acid; ALA, alpha-Linolenic Acid; EPA, Eicosapentaenoic Acid; DHA, Docosahexaenoic Acid; O3I, Omega-3 Index (EPA + DHA%).

### *3.2. Omega-3 status following ad libitum fish oil supplementation*

At the completion of the season, thirteen ($n$ = 13) cyclists were available to provide a blood sample. Of these, 54% (7 out of 13) participants reported achieving two capsules per day (1,118 mg EPA + 458 mg DHA) on every day over the course of the season. In contrast, 46% (6 out of 13) participants reported consuming the omega-3 supplement, but not consistently which was best described as 2 – 3 times per week on average. For the 7 riders who self-reported meeting the daily dose recommendations they significantly increased their O3I (pre-season mean = 6.81%, SD = 1.97; post-season mean = 9.06%, SD = 1.06, $p$ < 0.01, Bonferroni adjusted) where in contrast, the six riders who reported inconsistent and sub-optimal intake of the supplement, their O3I remained unchanged (pre-season mean = 7.11%, SD = 0.75; post-season mean = 7.09%, SD = 0.47, $p$ = 0.97, Bonferroni adjusted) (Table 2). Moreover, the elevation of the O3I within the optimal supplement group was underpinned by a significant elevation of whole blood EPA ($p$ = 0.01, Bonferroni adjusted) and DHA ($p$ = 0.01, Bonferroni adjusted) over the duration of the season and this was not observed in the sub-optimal supplement group (EPA $p$ = 0.99 and DHA $p$ = 0.99, Bonferroni adjusted (Table 2).

## 4. Discussion

This quasi-experimental study investigated the effectiveness of translating a laboratory-based minimal LCn-3PUFA dose to improve the omega-3 status of professional UCI road cyclists across a competitive cycling season. In contrast to other studies in cohorts of elite athletes, we observed higher than expected pre-season baseline omega-3 status (mean O3I > 7%, mean n-6/n-3 < 6, mean AA/EPA < 11) suggesting pre-existing differences in habitual dietary influences that included provisions of 1 – 2 fish meals per week via the team menu. In response to profiling, the omega-3 status was significantly improved in those riders who closely followed the advice of optimal fish oil intake. Yet these same parameters remained unchanged in those riders who did not consistently achieve the daily recommendations over the course of the competitive season. Our novel observations are the first to highlight the efficacy of translating laboratory-based EPA + DHA dosing strategies (Hingley et al., 2017) to real-world *ad libitum* provisions of fish oil in a professional sporting environment. Such an outcome emphasises the critical role of fatty acid profiling for performance nutrition in elite athletes, especially given the complex role of omega-3 status in supporting optimal skeletal and cardiac muscle physiology.

Pre-season baseline mean O3I (7.07%) was higher relative to previous published data. Studies of elite athletes prior to fish oil or dietary intervention are limited but have consistently demonstrated a mean O3I < 5% in collegiate athletes (Anzalone et al., 2019; Drobnic et al., 2017; Heileson et al., 2021; Ritz et al., 2020) and Canadian elite rugby 7s players (Armstrong et al., 2021). Furthermore, in a cohort of 106 German elite winter-endurance athletes consuming their usual training diet, the mean O3I was reported to be < 5% and only one individual was > 8% (von Schacky et al., 2014). It is noteworthy in the current study, those five riders who identified as high for omega-3 status at baseline also reported some use of the omega-3 supplement in the months before the sample. Moreover, although speculative in nature, the higher group mean O3I observed in these riders suggests some habitual consumption of a Mediterranean influenced rather than typical Western-style diet. For example, the team was provided with 1 – 2 fish servings per week. This baseline omega-3 status contrasts with the very low O3I (4.13%) reported in vegan endurance triathletes whose diet is void of LCn-3PUFA (Craddock et al., 2022). Mediterranean diets tend to include a larger percentage of LCn-3PUFA from marine sources. For example, in Spain, fish consumption is approximately 55 g/day vs. approximately 16 g/day in the United States (Blasbalg et al., 2011; Engeset et al., 2006). It is also well-established that the typical Western-style diet is less than optimal in providing LCn-3PUFA (Micha et al., 2014) and this can be implied from global erythrocyte O3I concentrations (Stark et al., 2016). The difference in mean O3I values of the current study relative to previous literature also strengthens the argument for the universal use of baseline erythrocyte EPA + DHA concentration measurements (Anthony et al., 2021), as part of best practice omega-3 study design (Anthony et al., 2023).

The current study demonstrated effective translation of laboratory-based LCn-3PUFA dosing evidence into a real-world elite sporting team with the pre-defined goal for riders to optimise and maintain their omega-3 status across the competitive season.

Table 2: Whole blood relative fatty acid profile (%) and red blood cell Omega-3 status in professional team riders before and after 16-18 weeks of *ad libitum* provision of fish oil with concurrent advice.

| | Sub-optimal FO Intake ($n$ = 6) | | Optimal FO Intake ($n$ = 7) | | ANOVA ($p$-values) | | |
|---|---|---|---|---|---|---|---|
| Fatty acid | Pre Mean (SD) | Post Mean (SD) | Pre Mean (SD) | Post Mean (SD) | Group | Time | Interaction |
| Σ SFA | 35.24 (2.31) | 35.19 (1.22) | 36.12 (1.30) | 35.40 (0.60) | 0.47 | 0.28 | 0.34 |
| Σ MUFA | 21.99 (2.59) | 20.93 (1.48) | 23.59 (1.32) | 21.14 (1.33) | 0.31 | < 0.01 | 0.15 |
| Σ PUFA | 42.77 (2.18) | 43.88 (1.07) | 40.29 (1.75) | 43.45 (1.71) | 0.09 | < 0.01 | 0.08 |
| LA | 23.96 (2.12) | 24.44 (2.52) | 21.59 (1.86) | 22.53 (1.66) | 0.07 | 0.08 | 0.54 |
| AA | 9.24 (1.57) | 8.54 (1.70) | 9.07 (0.67) | 8.19 (0.86) | 0.69 | 0.01 | 0.71 |
| Σ n-6 PUFA | 36.15 (2.37) | 36.02 (1.55) | 33.90 (2.42) | 33.71 (2.16) | 0.06 | 0.80 | 0.97 |
| ALA | 0.32 (0.09) | 0.31 (0.04) | 0.26 (0.05) | 0.30 (0.06) | 0.31 | 0.56 | 0.23 |
| EPA | 1.39 (0.47) | 1.35 (0.33) | 1.21 (0.79) | 2.37 (0.74)* | 0.12 | 0.04 | 0.03 |
| DHA | 3.68 (0.35) | 3.70 (0.32) | 3.62 (1.10) | 4.42 (0.72)* | 0.40 | 0.02 | 0.03 |
| Σ n-3 PUFA | 6.61 (0.83) | 7.86 (0.60) | 6.39 (2.00) | 9.74 (0.88)* | 0.16 | < 0.01 | 0.03 |
| n-6/n-3 | 5.57 (1.05) | 4.61 (0.51) | 5.81 (1.98) | 3.49 (0.50) | 0.41 | < 0.01 | 0.14 |
| AA/EPA | 7.89 (4.97) | 6.89 (2.93) | 10.42 (5.93) | 3.86 (1.59) | 0.88 | 0.04 | 0.12 |
| O3I | 7.11 (0.75) | 7.09 (0.47) | 6.81 (1.97) | 9.06 (1.06)* | 0.16 | 0.02 | 0.02 |

*Note:* Data collected from professional team riders that reportedly followed (Optimal fish oil intake; $n$ = 7) or reportedly did not follow (Sub-optimal fish oil intake; $n$ = 6) supplementation advice. Abbreviations: Int., Interaction; FO, fish oil; SFA, Saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA polyunsaturated fatty acids; LA, Linoleic Acid; AA, Arachidonic Acid; ALA, alpha-Linolenic Acid; EPA, Eicosapentaenoic Acid; DHA, Docosahexaenoic Acid; O3I, Omega-3 Index (EPA + DHA%). * $p < 0.05$ within supplement group pre vs. post (corrected for multiple comparisons using the Bonferroni procedure).

Riders were advised to consume two fish oil capsules per day, providing a daily dose of 1,118 mg EPA + 458 mg DHA. Whilst this is approximately double the daily intake of LCn-3PUFA required to achieve an elevation in O3I in laboratory studies (Hingley et al., 2017; Macartney et al., 2014; Macartney et al., 2021b) this recommendation was employed as there was less than two months to the start of the first grand tour. It is important to recognise that time-course investigations demonstrate tissue incorporation of EPA + DHA typically occurs over several months (Owen et al., 2004). Thus, a slightly higher dose was chosen to ensure marked changes in blood EPA + DHA concentrations within the team's defined time-constraints. To the authors' knowledge, this study is the first to consider the effect of supplementation duration in professionally trained and managed elite athletes with a focus on extreme endurance performance and fatigue management. In fact, future research should aim to vary both the dose and duration of the chosen omega-3 supplementation intervention until each individual athlete achieves a pre-defined change in their membrane omega-3 status, noting this would require serial blood sampling and according to the most recent recommendations for conducting omega-3 studies in training groups (Anthony et al., 2023)

The novel omega-3 evaluation and advice program used in this study significantly improved the omega-3 status in riders ($n$ = 7) that self-reported following their fish oil intake advice across the competitive season (16 – 18 weeks). Whereas omega-3 status remained unchanged in riders ($n$ = 6) that self-reported they did not strictly follow advice over the course of the competitive season. Observational analysis of elite athletic groups has revealed that despite 39% of National Collegiate Athletic Association (NCAA) athletes consuming the recommended amount of dietary fish per week, only 6% met the requirement for EPA + DHA intake (Ritz et al., 2020). Given that the current study was able to demonstrate riders which self-reported as not strictly following supplementation advice still achieved an O3I > 7%, future work investigating the effect of supplemental fish oil in elite athletes should focus on also using human dietary achievable doses ranging from 500 mg/day – 1500 mg/day of long chain omega-3 EPA + DHA. Doses beyond the higher end of this range would require approximately 6 – 10 standard fish oil capsules per day and therefore may become a burden upon the individual's dietary goals with little additional improvement in their omega-3 status.

This study demonstrates that evaluating the omega-3 status of elite cyclists can improve individual advice for the consumption of EPA + DHA without impacting the nutritional plans and goals which typically include total energy requirements and the provision of carbohydrate and protein. However, questions regarding the interaction of omega-3 status with exercise training have been raised. Runners taking part in arduous training were reported to have an association of a higher weekly running distance with a lower O3I and higher AA/EPA (Davinelli et al., 2019). In the same instance, the O3I of National Football League players was also reported to decrease over the competition season (Blue et al., 2019). In contrast, in response to physical activity, exercise trained individuals have been demonstrated to increase skeletal muscle membrane incorporation of LCn-3PUFA independent of fibre type (Andersson et al., 2000). Our current findings support this by demonstrating that elite riders who consistently consume two fish oil capsules per day (1,118 mg EPA + 458 mg DHA) elevated and/or maintain their already optimal omega-3 status alongside the arduous nature of their training and competition in grand tours. Accordingly, LCn-3PUFA evaluation and supplementation advice appears to be an effective strategy to achieve an optimal omega-3 status despite the presence of very high training volumes and exercise intensity.

Future studies may clarify whether the novel observations highlighting the efficacy of translating laboratory-based EPA + DHA dosing strategies to real-world *ad libitum* provisions of supplemental fish oil in a professional sporting environment are also evident for females. Whilst this investigation did not include females, serum LCn-3PUFA have been demonstrated to differ in women (↓ EPA yet ↑ DHA) compared to males (Mingay et al., 2016) and this may be related to differences in fatty acid metabolism due to the effects of sex hormones (Decsi & Kennedy, 2011). Additionally, the quasi-experimental study design resulted in follow up samples from ten riders being lost either from injury, illness, team list changes or other uncontrollable factors. Nevertheless, this study is an important first step in the critical role of using fatty acid profiling to inform evidence-based LCn-3PUFA dosing strategies for performance nutrition in elite athletes.

In conclusion, evaluating erythrocyte LCn-3PUFA composition of riders in an elite cycling team has demonstrated that there is a wide range of O3I scores in a team of elite athletes professionally racing. Importantly, an elite rider with a consistent daily intake of two high quality omega-3 capsules providing 1,118 mg EPA + 458 mg DHA was able to achieve and maintain optimal omega-3 status (O3I > 8%; n-6/n-3 < 5; AA/EPA < 11) whilst training for and competing in the grand tours. The long-term approach is to determine if manipulating cell membrane incorporation in favour of EPA + DHA can physiologically support the stress of endurance training and competition, especially over the longer-term career and lifespan of elite athletes.

## Conflict of Interest

The authors declare no conflict of interests.

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# Determinants and longitudinal changes of serum 25-hydroxyvitamin D during basic military training in female New Zealand Army recruits

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ABSTRACT

*Suboptimal vitamin D status is reported to negatively impact military readiness. This longitudinal study aimed to describe vitamin D status during basic military training (BMT) and identify determinants of serum 25-hydroxyvitamin D (25(OH)D) in female recruits in the New Zealand Army. Serum 25(OH)D was measured during week one (baseline) and week 16 (end) of BMT (n = 87) and further characterised by ethnicity and season. Following univariate analysis, age, body mass index (BMI), ethnicity, season, exercise, and serum ferritin were analysed as determinants of 25(OH)D at baseline using a hierarchical linear regression model. From baseline to end, mean ± SD 25(OH)D was 102.5 ± 33.6 vs 67.4 ± 22.6 nmol/L (p < 0.001) for BMT commenced in summer and 67.4 ± 21.5 vs 73.8 ± 18.9 nmol/L (p = 0.033) for BMT commenced in winter. Regardless of the season basic training commenced, less than one-third of participants overall had sufficient (≥ 75 nmol/L) vitamin D status at the end. Age, BMI, ethnicity, and season explained 48.2% of the variance in 25(OH)D at baseline. Wintertime and being of Pacific or Māori ethnicity were the strongest negative determinants of 25(OH)D at baseline. These results suggest seasonal UVB exposure is a major determinant of 25(OH)D and Pacific and Māori ethnic groups are particularly at risk of suboptimal vitamin D status. Education, screening, and early supplementation are recommended to prevent suboptimal vitamin D status during BMT.*

## 1. Introduction

Diminished vitamin D status is a concern for all military personnel. Observational studies in military recruits suggest an association between reduced serum 25-hydroxyvitamin D (25(OH)D) concentration and increased risk of stress fractures (Burgi et al., 2011; Davey et al., 2016; Ruohola et al., 2006), longer recovery time from stress fractures (Richards & Wright, 2018), impaired aerobic fitness (Carswell et al., 2018) and increased incidence of upper respiratory tract infections (Harrison et al., 2021; Laaksi et al., 2007) in otherwise healthy recruits. Injury and illness during basic military training (BMT) have considerable personal and organisational impacts with delays in completing training, medical and rehabilitation costs, and potential discharge from military service.

Evidence for the role of vitamin D in skeletal health is robust. The biologically active form of vitamin D, 1,25-dihydroxyvitamin D (1,25(OH)$_2$D) stimulates intestinal absorption of dietary calcium and phosphorus. This maintains homeostasis of serum concentrations, essential for bone mineralisation (DeLuca, 2004)

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and neuromuscular function (Holick et al., 2011). Vitamin D status has therefore been identified as a modifiable risk factor in reducing the burden of musculoskeletal injuries during BMT. This is particularly relevant for female recruits, where the incidence of stress fractures has been reported up to three times higher than males (Jones et al., 1993; Knapik et al., 2012; Moran et al., 2008).

Most female recruits have insufficient vitamin D status at the end of BMT (Andersen et al., 2010; Carswell et al., 2018; Gaffney-Stomberg et al., 2019; Lutz et al., 2012). This decline is likely influenced by a lack of casual sun exposure, the predominant source of vitamin D for most people. In New Zealand, higher latitudes have been shown to decrease vitamin D status (Ministry of Health, 2012). However, no studies have investigated vitamin D status in a New Zealand military population. In female recruits in the United States, 25(OH)D at baseline and the end of BMT has been associated with ethnicity (Andersen et al., 2010; Lutz et al., 2012) and the season training commenced (Gaffney-Stomberg et al., 2019). Inadequate dietary vitamin D intake may also contribute to diminishing 25(OH)D (Lutz et al., 2019; Lutz et al., 2012). It is important to confirm these findings in populations outside of the United States that are ethnically diverse. Latitude and seasonal changes may also confer differences in outcomes that are not transferable between populations. In addition, multiple other factors, including body composition, physical activity and smoking status have been reported as significant predictors of 25(OH)D in large scale studies (Kuhn et al., 2014; Liu et al., 2010; Millen, 2010). The objectives of this longitudinal study were therefore to describe the vitamin D status of female recruits in the New Zealand Army during BMT and to investigate potential determinants at baseline.

## 2. Methods

### *2.1. Participants*

All female recruits enlisted in the New Zealand Army from February 2014 to March 2016 were eligible and invited to participate in this longitudinal cohort study. New Zealand Army recruits undertake 16-weeks of BMT at Waiouru Military Camp, latitude 39°S and 792 m above sea level. All procedures involving human subjects were approved by the Massey University Human Ethics Committee: Southern A (Application – 13/85). Investigators also adhered to the Defence Force Order 3 (New Zealand Defence Force, 19 November 2020), which prescribes the policy relating to the conduct and approval of personnel research. Volunteers provided informed and written consent. The sample size was determined by the feasibility of recruitment.

### *2.2. Study procedures*

Data was collected over nine intakes of BMT, categorised by the season BMT started. Summer intakes ($n = 5$) started in February or early March (end of summer) and ended in May (late autumn/fall) or June (early winter). Winter intakes ($n = 4$) started in July or August (winter) and ended in October or November (spring). Serum 25(OH)D was measured during week one (baseline) and week 16 (end) of BMT. Body composition, demographic and lifestyle data were collected at baseline.

### *2.3. Basic military training*

Basic military training is a 16-week, residential course designed to take a person from a civilian to a competent and self-disciplined soldier. Core military skills covered include weapon training, first aid, navigation, drill, fieldcraft and military law. Long periods of training occur outdoors. All meals, snacks and beverages are provided. Dietary supplements are not permitted unless prescribed by a medical doctor. Recruits primarily wore a combat uniform, consisting of long trousers, a long-sleeve shirt, boots, and a wide-brimmed hat.

### *2.4. Blood sampling and analysis*

A fasted venepuncture blood sample of 18ml was collected between 0600 and 0730 hours at baseline and the end. No participants exercised in the 8-hours prior to blood sampling. Serum 25(OH)D was analysed using a Sciex 4000 QTRAP liquid chromatography-tandem-mass spectrometer (LC-MS/MS) (AB Sciex LLC, Framingham, MA, United States) by Canterbury Health Laboratories. Samples were analysed using deuterated 25(OH)D as an internal standard. External quality control was provided by the Vitamin D External Quality Assessment Scheme. Inter-assay coefficients of variation (CV) ranged from 6% at 25(OH)D ≥ 150 nmol/L to 12% at < 25 nmol/L. The LC-MS/MS is the proposed gold standard for assays and enhances comparability between studies (Alexandridou et al., 2021). There is emerging evidence of a relationship between vitamin D and iron status, particularly through the effects of vitamin D on hepcidin (Shoemaker et al., 2022), the iron metabolism regulator (Nemeth et al., 2004). Inflammation increases hepcidin expression (Daher et al., 2017). The Cobas® 6000 (Roche Diagnostics, Indianapolis, IN, United States) was used to analyse serum ferritin (SF) as a marker of iron status, using the electrochemiluminescence immunoassay, e601 and C-reactive protein (CRP) as a marker of inflammation, using the two-point end method with an immunoturbidimetric assay, c501. Medlab Whanganui analysed SF and CRP. Both laboratories are accredited with International Accreditation New Zealand. Using 25(OH)D, vitamin D status was categorised as deficient (< 50 nmol/L), insufficient (50 – 74 nmol/L) or sufficient (≥ 75 nmol/L) (Holick et al., 2011). All concentrations < 75 nmol/L were referred to as suboptimal.

### *2.5. Ethnicity*

In New Zealand, the concept of prioritised ethnicity is the most common methodology used to classify ethnic groups in the health and disability sector (Ministry of Health, 2017). In addition, this method is particularly favoured for regression models (Boven et al., 2020). Using the concept of prioritised ethnicity, participants could self-identify with multiple ethnic groups. Responses were then prioritised into a single ethnic group in the following order: Māori, Pacific and New Zealand European (Ministry of Health, 2017).

### *2.6. Body composition*

Body composition measures were determined at baseline. Prior to all measures, the participants fasted overnight, performed no physical activity for at least 8-hours prior, urinated prior to testing, wore shorts and a t-shirt, and removed all jewellery. Height (m) was measured using a SECA 213 portable stadiometer (German Healthcare Export Group, Bonn, Germany) by a trained researcher. Body mass (kg) and body fat percentage were measured via bioelectrical impedance analysis using the InBody$_{230}$ (Biospace Co. Ltd., Seoul, South Korea). Body mass index (BMI) was calculated as mass (kg)/height (m$^2$).

### 2.7. Lifestyle

A questionnaire was administered at baseline via SurveyMonkey (Momentive Inc., San Mateo, United States). Smoking status was determined by the question, 'do you smoke cigarettes?'. Responses of 'never' and 'I used to' were categorised as 'no'. Responses of 'yes, everyday' and 'yes, occasionally' were categorised as 'yes'. Education level was investigated by the question, 'what is the highest level of education you have received?'. Responses included the New Zealand National Certificate of Educational Achievement (NCEA). The options were 'NCEA Level 1', 'NCEA Level 2', 'NCEA Level 3', 'tertiary certificate/diploma' and 'tertiary degree'. Tertiary certificate/diploma and degree were collapsed to tertiary qualification. The NCEA levels of 1, 2 and 3 are equivalent to study in grades 10, 11 and 12, respectively at a secondary school in the United States. Weekly exercise habits were determined by the question, 'in the past 4-weeks, how many hours per week did you spend exercising at an intensity that raised your heart rate?'. Response options were '< 3.0-hours', '3.0-5.9-hours', '6.0-8.9-hours' and '≥ 9.0-hours.'

### 2.8. Statistical approach

All statistical analyses were performed using IBM SPSS Statistics, Version 28.0 (Armonk, NY, IBM Corp). The Kolmogorov-Smirnov test and box plots were used to assess the data for normality. A $p$ value $< 0.05$ was considered statistically significant. Changes in 25(OH)D were investigated using paired *t*-tests. Independent *t*-tests investigated any difference in 25(OH)D between participants that finished BMT and participants that did not. Comparison of mean values of 25(OH)D between ethnicity groups at baseline and the end were investigated using one-way analysis of variance (ANOVA). A subsequent Tukey HSD test identified significant differences between the groups.

Simple linear regression analysis was performed to identify potential determinants associated with 25(OH)D at baseline. These determinants included age, BMI, body fat percentage, SF and CRP, entered as continuous variables; and season and smoking status, entered as binary variables. Dummy categorical variables were created and entered for ethnicity and exercise, with New Zealand European and < 3.0-hours the reference categories, respectively. Variables with a univariate $p < 0.20$ (age, BMI, ethnicity, season, exercise, and SF) were then entered into a hierarchical linear regression analysis. This value was chosen as univariate $p$'s $\geq 0.20$ were considered unlikely to contribute any unique variance to a model containing other potential determinants of 25(OH)D. At each step, the variables were controlled for those at the same level and the levels above. Assumptions for the regression model were defined as a Durbin-Watson statistic between 1.5 and 2.5 for autocorrelation of residuals, a Variance Inflating Factor < 5 for assessment of multicollinearity and a satisfactory normal P-P plot of regression standardised residual.

## 3. Results

Of the 108 female recruits invited to take part in this study, 106 volunteered to participate. Eighteen participants did not finish BMT: 14 incurred injuries (including five medically diagnosed stress fractures) and were removed from their initial course, and four participants self-withdrew. One participant was excluded due to supplementation with oral vitamin D3 during BMT. Following these exclusions, 87 participants (age = 19.2 ± 2.2 years; height = 165.1 ± 5.4 cm; body mass = 65.5 ± 9.3 kg; body mass index = 24.0 ± 2.8 kg/m$^2$; body fat percentage = 26.8 ± 5.4%) were included in the analysis. One participant consumed a vitamin D supplement before BMT commenced; however, their vitamin D status was deficient at baseline. Therefore, their supplement use did not impact further analysis and they were included in the results presented. Table 1 describes the characteristics of study participants at baseline.

Table 1: Characteristics of participants at baseline of basic military training (*n* = 87).

| **Characteristic** | ***n*** | **%** |
|---|---|---|
| **Ethnicity** | | |
| NZ European | 51 | 58.6 |
| Māori | 26 | 29.9 |
| Pacific | 10 | 11.5 |
| **Season** | | |
| Summer | 61 | 70.1 |
| Winter | 26 | 29.9 |
| **Education** | | |
| NCEA Level 1 | 3 | 3.4 |
| NCEA Level 2 | 25 | 28.7 |
| NCEA Level 3 | 45 | 51.7 |
| Tertiary Qualification | 14 | 16.1 |
| **Smoker** | | |
| Yes | 10 | 11.5 |
| No | 77 | 88.5 |
| **Exercise hours per week**[a] | | |
| < 3.0 | 13 | 14.9 |
| 3.0 – 5.9 | 38 | 43.7 |
| 6.0 – 8.9 | 23 | 26.4 |
| ≥ 9.0 | 13 | 14.9 |

*Note:* [a]Exercise at an intensity that elevated the heart rate. Abbreviations: NZ, New Zealand; NCEA, National Certificate of Educational Achievement.

Overall, the mean ± SD 25(OH)D declined during BMT from 92.0 ± 34.4 nmol/L at baseline to 69.3 ± 21.7 nmol/L at the end, $p < 0.001$. There was no significant difference in 25(OH)D at baseline between those participants that finished BMT and the 18 participants that did not. From baseline to the end, mean ± SD 25(OH)D was 105.2 ± 33.7 to 76.3 ± 17.4 nmol/L ($p < 0.001$) for

New Zealand Europeans, 78.2 ± 28.2 to 65.5 ± 24.5 nmol/L ($p$ = 0.002) for Māori, and 60.8 ± 13.5 to 43.7 ± 9.7 nmol/L ($p$ = 0.460) for Pacific. Figure 1 and Table 2 display ethnic differences in serum 25(OH)D and vitamin D status, respectively.

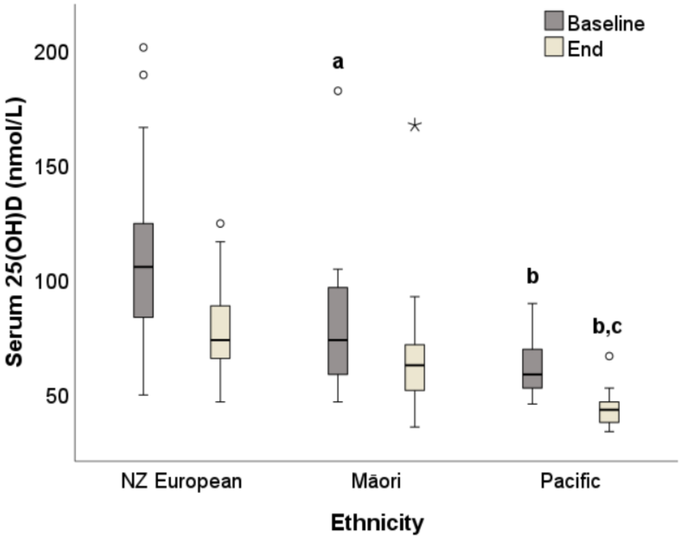

Figure 1: Boxplot of serum 25-hydroxyvitamin D at baseline and end of basic military training by ethnicity. Abbreviations: 25(OH)D, serum 25-hydroxyvitamin D; NZ, New Zealand. Boxes represent the middle 50th percentile. Vertical lines represent the 10th and 90th percentiles. Lines inside the box represent the median values. ◦Values 1.5 times the interquartile range. *Values 3 times the interquartile range. [a]$p$ = 0.001 between Māori and NZ European, [b]$p < 0.001$ between Pacific and NZ European and [c]$p < 0.001$ between Pacific and Māori.

Table 2: Vitamin D status at baseline and the end of basic military training by ethnicity and season of intake ($n$ = 87).

| | Sufficient[a] | | Insufficient[a] | | Deficient[a] | |
|---|---|---|---|---|---|---|
| | *n* | % | *n* | % | *n* | % |
| **Baseline** | | | | | | |
| Total | 54 | 62.1 | 27 | 31.0 | 6 | 6.9 |
| NZ European | 41 | 80.4 | 9 | 17.6 | 1 | 2.0 |
| Māori | 12 | 46.2 | 11 | 42.3 | 3 | 11.5 |
| Pacific | 1 | 10.0 | 7 | 70.0 | 2 | 20.0 |
| **End** | | | | | | |
| Total | 28 | 32.2 | 44 | 50.6 | 15 | 17.2 |
| NZ European | 24 | 47.0 | 26 | 51.0 | 1 | 2.0 |
| Māori | 4 | 15.4 | 16 | 61.5 | 6 | 23.1 |
| Pacific | 0 | 0 | 2 | 20.0 | 8 | 80.0 |
| **Summer** | | | | | | |
| Baseline | 47 | 77.0 | 14 | 23.0 | 0 | 0 |
| End | 18 | 29.5 | 30 | 49.2 | 13 | 21.3 |
| **Winter** | | | | | | |
| Baseline | 7 | 26.9 | 13 | 50.0 | 6 | 23.1 |
| End | 10 | 38.5 | 14 | 53.8 | 2 | 7.7 |

*Note:* [a]Serum 25(OH)D ≥ 75 nmol/L (sufficient), 50 – 74 nmol/L (insufficient), and < 50 nmol/L (deficient). NZ, New Zealand.

Across seasons, from baseline to the end, the mean ± SD 25(OH)D was 102.5 ± 33.6 vs 67.4 ± 22.6 nmol/L ($p < 0.001$) for BMT commenced in summer ($n$ = 61) and 67.4 ± 21.5 vs 73.8 ± 18.9 nmol/L ($p$ = 0.033) for BMT commenced in winter ($n$ = 26). See Table 2 for further analysis. Unequal group sizes in the winter intakes prevented further analysis of 25(OH)D by season and ethnicity.

The hierarchical linear regression model for predicting serum 25(OH)D at baseline is illustrated in Table 3. Age, ethnicity, and season were significant determinants of 25(OH)D at baseline, accounting for 7.8%, 17.1%, and 20.8% of the unique variance, respectively. Excluding the non-significant exercise and SF variables, the final model explained 48.2% of the variance in 25(OH)D.

## 4. Discussion

This is the first study to investigate the vitamin D status of females in the New Zealand Army and potential vitamin D determinants. During BMT, 25(OH)D declined significantly for participants that commenced BMT in summer and increased significantly for those that commenced BMT in winter. Despite the increase observed for the winter intakes, two-thirds of all participants had suboptimal vitamin D status at the end of BMT, regardless of the season that they commenced training. For Pacific and Māori, 100% and 85% of participants had suboptimal vitamin D status following 16-weeks of BMT, respectively. Wintertime and being of Pacific or Māori ethnicity were the strongest determinants and inversely associated with 25(OH)D at baseline, when age and body composition were controlled for. This model explained 48.2% of the variance in 25(OH)D at baseline.

The results of this study reflect the findings from the 2008/09 New Zealand Adult Nutrition Survey, in which the prevalence of vitamin D deficiency was highest during late winter and early spring (Ministry of Health, 2012). As the major determinant of 25(OH)D is ultraviolet beta (UVB) exposure, New Zealand's distance from the equator, lower angle of the sun, greater cloud coverage and increased clothing cover during these months; coupled with a gradual loss in accumulated 25(OH)D from summer will have contributed to the seasonal variation (Livesey et al., 2007; Ministry of Health, 2012). The fact that much of BMT occurs outdoors during daylight hours suggests some casual sun exposure during spring supported positive changes in 25(OH)D for winter recruits, rather than further decline as suggested by the New Zealand population data. The findings in this study are similar to those in females and males completing 12-weeks of BMT in the United States Marines without vitamin D supplementation. For participants that commenced BMT in winter, a significant mean 25(OH)D increase ($p < 0.05$) was also reported during BMT. However, the mean 25(OH)D concentration at the end of training failed to reach vitamin D sufficiency (Gaffney-Stomberg et al., 2019).

New Zealand Europeans had the highest vitamin D status, followed by Māori, then Pacific female recruits at all time points throughout this study. This reflects the situation within the New Zealand population, where the mean annual 25(OH)D for women

Table 3: Hierarchical linear regression model for determinants of serum 25-hydroxyvitamin D at baseline of basic military training ($n = 87$).

| **Predictor** | | | ***B*[a]** | ***SE B*** | **95% CI** | **β[b]** | ***R² Change*** |
|---|---|---|---|---|---|---|---|
| Step 1 | | | | | | | |
| | Age | | -4.428 | 1.650 | [-7.708, -1.148] | -0.280 | 0.078$^{*}$ |
| Step 2 | | | | | | | |
| | Age | | -4.388 | 1.637 | [-7.644, -1.132] | -0.277 | |
| | BMI | | -1.931 | 1.272 | [-4.461, 0.598] | -0.157 | 0.025 |
| Step 3 | | | | | | | |
| | Age | | -3.059 | 1.560 | [-6.162, 0.044] | -0.193 | |
| | BMI | | -1.172 | 1.175 | [-3.509, 1.166] | -0.095 | |
| | Ethnicity | NZ European | | | Reference | | |
| | | Māori | -22.303 | 7.582 | [-37.385, -7.220] | -0.298 | |
| | | Pacific | -41.124 | 10.571 | [-62.152, -20.096] | -0.383 | 0.171$^{**}$ |
| Step 4 | | | | | | | |
| | Age | | -2.376 | 1.331 | [-5.024, 0.273] | -0.150 | |
| | BMI | | -0.159 | 1.014 | [-2.178, 1.859] | -0.013 | |
| | Ethnicity | NZ European | | | Reference | | |
| | | Māori | -21.714 | 6.445 | [-34.538, -8.890] | -0.290 | |
| | | Pacific | -46.275 | 9.030 | [-64.242, -28.307] | -0.431 | |
| | Season | Summer | | | | | |
| | | Winter | -34.927 | 6.127 | [-47.119, -22.736] | -0.467 | 0.208$^{**}$ |

*Note:* $F(5, 81) = 15.054$, $p < 0.001$, $R^2 = 0.482$, adjusted $R^2 = 0.450$. [a]Unstandardised coefficients. [b]Standardised coefficients. $^{*}p < 0.01$. $^{**}p < 0.001$. Age and BMI were entered as continuous variables. Ethnicity and season were entered as categorical variables. Abbreviations: BMI, body mass index; NZ, New Zealand.

aged 15 years and over was 62.4 nmol/L, 57.2 nmol/L and 46.0 nmol/L for the total population sample, Māori, and Pacific, respectively (Ministry of Health, 2012). Ethnicity is consistently a strong individual predictor of 25(OH)D in multivariable regression models (Bertrand et al., 2012; Knight et al., 2017; Liu et al., 2018; Nessvi et al., 2011). Ethnicity is likely related to many other factors that can reduce vitamin D status, both non-modifiable, such as genetics, skin colour and latitude, and modifiable, including physical activity levels, clothing cover, diet quality and tobacco smoking (Knight et al., 2017; Liu et al., 2018; Nessvi et al., 2011). Higher levels of melanin may reduce 25(OH)D in individuals with darker skin pigmentation, including those of Pacific and Māori ethnicity. Melanin absorbs sunlight, reducing its ability to trigger endogenous vitamin D production (Holick, 2007).

For BMT that commenced in summer and winter, the prevalence of suboptimal vitamin D at the end was 71% and 62%, respectively. These results support the findings of two studies in female recruits following completion of BMT in the United States Army at a training location of 34°N (Andersen et al., 2010; Lutz et al., 2012). For participants that commenced BMT at the end of summer, 75% had suboptimal vitamin D status at the end of training (Andersen et al., 2010). For participants that commenced BMT at the end of winter, the prevalence of suboptimal vitamin D status at the end of training was 64% and 92% for white and non-white participants, respectively (Lutz et al., 2012). Collectively these studies indicate that regardless of ethnicity, most female recruits have suboptimal vitamin D status at the end of BMT, if not also throughout BMT.

It has been proposed that excess adipose tissue sequesters vitamin D (Wortsman et al., 2000). In this study there was no significant association between 25(OH)D and BMI or body fat percentage at baseline. While Lutz et al. (2012) also reported no significant association with body composition in the total study population of female recruits in the United States, there was a positive association between baseline 25(OH)D and body fat percentage in non-white participants (Lutz et al., 2012). Gaffney-Stomberg et al. (2019) stated that the observed increase in 25(OH)D in recruits who began training in the winter was likely due to the release from endogenous fat stores. This was based on the finding that participants completing BMT during winter lost more body fat than those undertaking training during summer.

The incidence of medically diagnosed stress fractures during BMT has been reported up to 5% for men and 18% for women (Jones et al., 1993; Knapik et al., 2012; Moran et al., 2008). Up to 60% of those who sustain a stress fracture attrite from training (Friedl et al., 2008). Vitamin D status is a modifiable risk factor for stress fractures (Abbott et al., 2022; Bishop et al., 2020). Serum 25(OH)D ≥ 75 nmol/L has been linked with lower stress fracture rates in male military recruits (Davey et al., 2016; Ruohola et al., 2006). In female recruits in the United States Navy, there was a significant dose-response relationship of higher 25(OH)D with lower stress fracture risk, particularly of the tibia and fibula (Burgi et al., 2011). Females in the highest quintile of

25(OH)D (≥ 100 nmol/L) had a lower stress fracture risk than those in the lowest quintile (< 50 nmol/L), OR = 0.51, $p \leq 0.01$, 95% CI [0.34, 0.76], (Burgi et al., 2011).

In this study, two-thirds of participants overall had suboptimal vitamin D status at the end of BMT. In the five participants that incurred medically diagnosed stress fractures and did not finish BMT, they all had suboptimal 25(OH)D at baseline (range 44-68 nmol/L). It is therefore worth considering screening and supplementing recruits with 25(OH)D < 75 nmol/L at baseline to reduce stress fracture risk. Given it may take 2-3-months for vitamin D supplementation to improve status – education, screening and supplementation during the recruiting phase may be required to ensure a protective effect.

Comparisons between studies in the general population to investigate factors affecting vitamin D status are difficult due to the diversity of participants, controversy regarding 25(OH)D cut-offs, seasonality and factors adjusted for in the final model (Holick et al., 2011; Liu et al., 2010; Liu et al., 2018). Prediction models in adult representative samples have significant unexplained variability regarding the factors that affect vitamin D status (Bertrand et al., 2012; Kimlin et al., 2014; Knight et al., 2017; Kuhn et al., 2014; Liu et al., 2010; Lucas et al., 2013; Millen, 2010). This is likely the result of methodological errors in measuring predictor variables, serum 25(OH)D (Black et al., 2015) and lack of information regarding genetic factors and UVB exposure that considers clothing, cloud cover and the use of sunscreen (Bertrand et al., 2012). With minimal UVB exposure, dietary intake of vitamin D can contribute to achieving 25(OH)D targets. Dietary intake of vitamin D was not assessed in this study and at present, there is no data available to assess the usual intake in the New Zealand population. However, few foods are naturally rich sources or fortified with vitamin D in New Zealand. Dietary supplements are therefore likely to be the most effective method for individuals to increase their intake of vitamin D.

There are several strengths associated with this study. No previous investigations in female recruits have explored changes in 25(OH)D beyond 12-weeks. The extended duration of these results may be applicable to other female military populations with longer or consecutive training. A further strength is the location of 39°S. Previous research has encouraged studies in military personnel to be conducted at training locations approaching or greater than latitudes of 40° to measure the effects of more extreme environments on vitamin D status. While blood samples were collected at varying months across three years, the stable environment during BMT, regarding climatic conditions and the level of skin exposure is a strength.

A limitation of this study is that participants were not asked to describe their UVB exposure prior to BMT in terms of time spent outdoors for work, recreation, or physical activity; the region they lived in; and sun protection behaviours. While weekly exercise duration of a moderate to high intensity was measured; participants were not asked the frequency, time of day or whether the exercise occurred indoors or outdoors. These additional questions would have contributed to a greater understanding of participants' UVB exposure prior to BMT. In addition, there was no examination of dietary intake as a potential determinant of 25(OH)D. Although diet is a relatively modest contributor to vitamin D status compared to other predictors, it has contributed significantly towards the explained variance of 25(OH)D in multivariable regression models (Bertrand et al., 2012; Knight et al., 2017; Kuhn et al., 2014; Liu et al., 2018). However, these studies have primarily been conducted in North America and Europe where the fortification of food staples is common. In Australia, where the food supply and vitamin D fortification levels are similar to New Zealand, studies have not identified dietary vitamin D intake as a significant contributor to the explained variance in 25(OH)D (Kimlin et al., 2014; Lucas et al., 2013). Assessment of skin colour/type in this study may have provided more specificity than ethnicity, particularly between Māori and Pacific groups. However, studies have indicated that a strong association between ethnicity and 25(OH)D remained after melanin content (Knight et al., 2017) and skin type (Chan et al., 2010) were accounted for. While no participants in the current study identified as Indian, Middle Eastern or African, Bolland et al. (2008) demonstrated that these ethnic groups in New Zealand have lower mean 25(OH)D than Māori or Pacific groups and are at risk of vitamin D deficiency. It is recommended a low threshold for vitamin D supplementation is applied to recruits identifying as Māori, Pacific, Indian, Middle Eastern or African.

Future research should confirm these findings in an ethnically diverse population of male recruits in the New Zealand Army to ensure recommendations are targeted appropriately. In addition, the feasibility of education, screening, and supplementation during the recruiting phase is worth investigating. The impact of this early preventative approach could be assessed through the effect on vitamin D status and risk of musculoskeletal injuries during BMT. Establishing a consensus amongst clinicians and researchers for 25(OH)D sufficiency that promotes optimal musculoskeletal health, as well as general health, should be prioritised. This is particularly relevant in high-risk populations, such as military personnel with intense training periods and operational demands.

In conclusion, this study has demonstrated that 25(OH)D declined significantly for female recruits that commenced BMT in summer and increased significantly for those that commenced BMT in winter. Regardless of the season BMT commenced, two-thirds of participants overall had suboptimal vitamin D status at the end of 16-weeks of training. Seasonal UVB exposure was identified as a major determinant of 25(OH)D, and Pacific and Māori ethnic groups are particularly at risk of suboptimal vitamin D status. It is recommended that health practitioners working with military recruits focus on preventing suboptimal vitamin D status. This can be achieved through education, screening, and supplementation, before or at the commencement of BMT.

## Conflict of Interest

The authors declare no conflict of interests.

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# Inertial measurement unit analysis for providing greater diagnostic value during the modified 5-0-5 change of direction test

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ABSTRACT

*Timing gates are currently the most common piece of equipment for measuring change of direction (COD) performance, however, they provide only a total time metric. A better understanding of the kinematics and kinetics during a COD movement beyond total time would provide coaches with a more comprehensive understanding of COD movement and how it can be improved. Therefore, the aim of this study was to determine the reliability of an inertial measurement unit (IMU) insole for measuring peak acceleration, peak deceleration, maximum speed, and ground contact time during a modified 5-0-5 change of direction (COD) test. Additionally, the strength of association between these IMU variables and timing light metrics was explored. Ten elite female netball athletes (age = 24.9 ± 5.0 years, height = 180.1 ± 6.5 cm, weight = 81.3 ± 15.0 kg) performed a modified 5-0-5 COD test across three testing occasions. Analysis revealed moderate to excellent relative consistency (ICC = 0.57 – 0.94) and acceptable absolute consistency (CV = 1.8 – 9.5%). Correlations ranged from 0.04 to 0.95, with peak acceleration having the strongest correlation with total time (r = 0.95). It appears that IMU insoles can be used to reliably measure performance during a COD task and provide additional diagnostics beyond time metrics.*

## 1. Introduction

Change of direction (COD) movements are prevalent in both team and individual sports, and the ability to execute them effectively is considered crucial for achieving success in most sports (Barber et al., 2016; Morgan et al., 2022; Ryan et al., 2022b; Talty et al., 2022). COD tasks involve different phases such as acceleration, deceleration, turning/cutting, and reacceleration, as described by Ryan and colleagues (2021; 2022a). One common test that is used to measure 180° COD performance is the modified 5-0-5 COD test, however most researchers only quantify performance with total time (Barber et al., 2016; Gabbett, Kelly, & Sheppard, 2008; Taylor et al., 2019). A better understanding of the kinematics and kinetics during a COD movement, rather than just providing total time, would provide practitioners with a more comprehensive understanding of COD test performance and how it can be improved (Nimphius et al., 2018). Ryan and colleagues (2021) have aimed to improve the diagnostic capabilities of the test to provide measures of the different phases, however, more advanced technologies can complement this analysis.

Motion capture systems and force plates are considered the gold standard for movement analysis and are used to measure a suite of kinematic and kinetic variables, such as joint range of motion, movement velocities, step kinematics, magnitude, and orientation of ground reaction forces, and speed of COD movements (Marshall et al., 2014; McFadden, Daniels, & Strike, 2020). However, this equipment can be expensive and not easily applicable to field settings (Alanen et al., 2021). Other technologies such as Optojump has been used to quantify ground contact time during 180° COD tasks, with authors reporting

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moderate to good reliability (intraclass correlation coefficients [ICC's] = 0.52 – 0.89; coefficients of variation [CV's] = 10.0 – 10.6%) (Condello et al., 2020). Though this technology can be used in a field setting, it may be too expensive or impractical to incorporate into some team sport settings.

Inertial measurement units (IMUs) provide a portable and relatively inexpensive alternative to measuring and monitoring an athlete's performance, through the measurement of acceleration, position and orientation during practice and games (Chambers et al., 2015). IMUs may be a practical solution to measuring step kinematics, such as acceleration, deceleration, and ground contact time during in-sport movements such as 180° COD. Practitioners could use this information to guide their exercise prescription and improve athletic performance (Alanen et al., 2021). Many IMU companies use a lease model, for example, IMeasureU starts at $6600 USD per year, while Plantiga foot pods are $2000 USD per year. With IMUs becoming increasingly popular, it seems important to determine if IMU technology can reliably measure COD performance, both within and between sessions.

Several researchers have reported on the reliability of IMUs to quantify different aspects of COD performance (Balloch et al., 2020; Barreira et al., 2017; Meylan, Trewin, & McKean, 2017). For example, Balloch and colleagues (2020) determined the reliability of using IMU technology attached to the posterior trunk, at the upper thoracic vertebrae (T1–T5). They developed an algorithm that was able to automatically detect and record COD movements ranging from 45 – 180°. They reported good reliability for all angles measured (CV = 1.3 – 4.2%). Barreira and colleagues (2017) investigated the reliability of a trunk-mounted (placed on thoracic spine) accelerometer to measure player load during a side cut movement. The authors reported moderate to high correlations between trials and acceptable limits of agreement (from 17 to 41%). Though these researchers have reported reliable metrics for these IMUs, there appears to be two main limitations. Firstly, the location of the IMUs at the trunk may not give the best representation of the foot-ground interaction. IMUs placed on the trunk may move around due to the jarring associated with fast and explosive movements such as sprinting or changing direction. This could be overcome by using a foot mounted IMU placed in the sole of the shoe since the location is at the interface of the foot and shoe, enabling it to capture the initial impact of the foot during contact with the ground (Napier et al., 2021). The second limitation of trunk located IMUs is data extraction and processing. Many of the IMUs used by researchers do not provide instant performance results and need extensive amounts of post-processing before the data can be interpreted. This may be a disadvantage for many strength and conditioning coaches that work in the field with individual and team sport athletes that would benefit from instantaneous feedback.

There are several commercially available IMUs that are placed on (shoelace mounted) or within the shoes (mid-arch of an insole in placed of a standard running shoe insole) (Napier et al., 2021). Many of these shoelace mounted and insole IMUs are equipped with a 6-axis IMU sensor (3-axis accelerometer and 3-axis gyroscope), allowing researchers to measure individual limb performance and differences across limbs. Additionally, many of these commercially available IMUs come with software that calculates a range of different variables such as player load, maximum speed, peak acceleration, peak deceleration, and ground contact time. With the evolving nature of sports science and athlete monitoring, practitioners need to ensure that the devices and calculation methods used within the software are providing reliable performance metrics that can be used in the field. To the authors knowledge, at the time of this research, there was no study that had determined the reliability of an IMU placed at the foot, for measuring COD performance metrics.

Many authors have highlighted the importance of deceleration and acceleration ability (Hewit et al., 2011; Hewit, Cronin, & Hume, 2013; Ryan et al., 2022a) and ground contact time at the turn during a 180° COD task (Dos' Santos et al., 2017). Therefore, it would seem important to be able to easily quantify these metrics during a COD task. Hence, the aim of this study was to firstly, determine the inter-session reliability of the Plantiga Insole IMU for measuring peak acceleration, peak deceleration, maximum speed, and ground contact time during a modified 5-0-5 COD test. Secondly, it would seem important to determine the strength of association between firstly the different IMU variables and secondly between the IMU variables and timed metrics investigated by Ryan and colleagues (2021) previously. This will help determine whether these IMU variables can predict certain temporal aspects of performance or add further diagnostic value to this COD test. This will provide coaches with greater insight into athletes' performance capabilities and therefore become more targeted with programming and exercise prescription.

## 2. Methods

### 2.1. Experimental approach to the problem

Ten elite female netball athletes performed three maximal effort trials (each leg) of the modified 5-0-5 COD test, over three testing occasions, separated by seven days. In-shoe IMUs were fitted to each athlete and placed within their normal court shoes before the commencement of the warm-up. The variability of the COD performance was quantified using CVs and ICCs

### 2.2. Participants

Ten elite female netball athletes (age = 24.9 ± 5.0 years, height = 180.1 ± 6.5 cm, weight = 81.3 ± 15.0 kg) participated in this study. Athletes competed in the New Zealand netball premiership league and had a minimum of six years netball experience. Participants were required to be healthy and free of injury at the time of testing. All participants were provided with an information sheet and were required to fill out a written consent form prior to participating in this study. Participants were notified that they were free to withdraw from the study at any time. This research was approved by the Auckland University of Technology Ethics Committee (20/402).

### 2.3. Equipment

#### 2.3.1. Inertial measurement unit

Plantiga IMUs (Plantiga Technologies, Vancouver, Canada; sampling frequency 416 Hz) were used during this research. Plantiga insoles are 6-axis IMUs (triaxial accelerometer and triaxial gyroscope) and are placed under each mid-foot. Each IMU is small (42 × 47 × 3.4 mm), durable, and water and impact resistant (see Figure 1). These insoles were placed in the participants shoes prior to the warmup. Four different metrics were extracted from the IMU cloud and used for analysis. Maximum speed is the highest speed achieved over the course of the modified 5-0-5 COD test. Peak acceleration and deceleration metrics were also extracted from the cloud. Lastly, ground contact time (GCT) of the plant foot at the time of the turn was extracted for each trial.

Figure 1: Plantiga IMU Insole.

### 2.3.1. Timing lights

Dual beam timing gates (Swift Performance Equipment, New South Wales, Australia) were also used to quantify COD performance. Gates were set at 0, 2, and 4 m to isolate the phases of the 5-0-5 COD test (acceleration, deceleration, 180° turn, and reacceleration), a method previously used by Ryan and colleagues (2021). Timing gate height was set at 1 m, in approximate line with centre of mass. This set up produced five different splits, as well as a total 5-0-5 COD performance time. These times corresponded to the different phases of the modified 5-0-5 COD test as outlined in Figure 2. Once all the trials were complete, the IMU data was uploaded into the Plantiga cloud and stored on-board for later analysis.

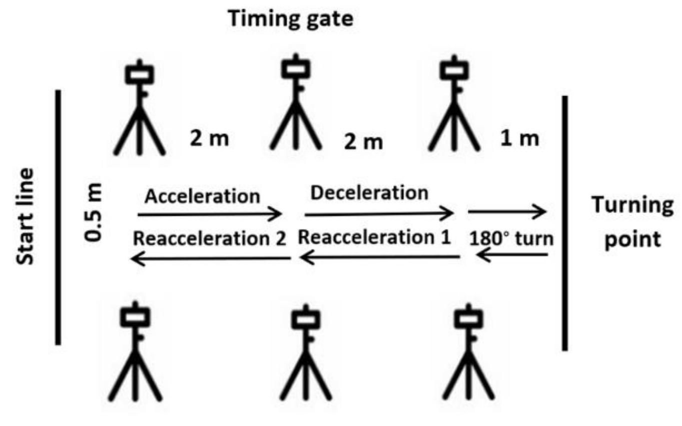

Figure 2: Modified 5-0-5 COD test with additional timing gates, producing five splits and total time.

### 2.4. Procedures

Testing was conducted on an indoor netball court. Athletes were instructed to wear the same clothing and footwear for all three sessions. All athletes were performing the modified 5-0-5 COD test on a weekly basis as part of their normal programming, and therefore did not require a familiarisation session. Each testing session was performed exactly 7 days apart, at the same location and time of day. Each testing session was 40 minutes, which included a standardised warm up consisting of lower body activation such as banded walks and squats, vertical, horizontal (bilateral and unilateral) jumps, progressive sprints (5, 10, and 20 m) and COD drills, building the intensity up to max effort.

For the modified 5-0-5 COD test, a modified set up was used as described by Ryan and colleagues (2021). Athletes started 0.5 m behind the start line (i.e., first timing gate) in a two-point split stance, with their preferred foot forward and began the test whenever they were ready. To ensure each athlete touched the line, the researchers observed each trial. If the athlete had a mistrial, they were given a retrial after three minutes of rest. Athletes were instructed to sprint 5 m and touch their foot on the COD line, perform a 180° turn on a specific leg and sprint 5 m back through the first timing gate. Three trials within each testing session were performed on each leg. Three minutes of rest was provided between trials to limit any fatigue effects.

### 2.5. Statistical analysis

All statistical analysis was performed using IBM SPSS statistical software package (version 27.0; IBM Corporation, New York, USA). Outlier and normality analysis was implemented on the raw data and means, and standard deviations were reported for all variables of interest. Absolute consistency between trials and sessions was quantified using CVs, where measures less than or equal to 10% were deemed acceptable (Lloyd et al., 2009). Relative consistency between trials and sessions was determined using ICC, using a two-way random average measures model (Koo & Li, 2016). Classification of ICC was deemed as follows: ‘very poor’ (< 0.20), ‘poor’ (0.20 – 0.49), ‘moderate’ (0.50 – 0.74), ‘good’ (0.75 – 0.90) or ‘excellent’ (> 0.90) (Buchheit & Mendez-Villanueva, 2013). Once reliability had been determined, relative left and right leg variables were compared for all IMU and timing lights metrics via paired t-tests. No statistical difference was found between left and right leg performance, therefore data was pooled and further analysed. Pearson correlation coefficients were used to determine the strength of association between IMU variables as well as timing light splits, and coefficients of determination ($R^2$) were used to quantify shared variance. The authors used a 50% shared variance threshold to determine the independence of variables (Baker, Wilson, & Carlyon, 1994; James et al., 2023; Young, Wilson, & Byrne, 1999).

## 3. Results

The inter-session variability of the IMU variables can be observed in Table 1. There appeared no systematic change between the variables, with the largest change observed between sessions 3 – 2 for the peak deceleration variable (-7.8%). In terms of absolute

Table 1: Inter-session variability of IMU variables.

| Variable | Mean ± SD | | | % Change in mean [95% CI] | | CV [95% CI] | | ICC [95% CI] | |
|---|---|---|---|---|---|---|---|---|---|
| | Session 1 | Session 2 | Session 3 | Session 2 – 1 | Session 3 – 2 | Session 2 – 1 | Session 3 – 2 | Session 2 – 1 | Session 3 – 2 |
| Max speed (m/s) | | | | | | | | | |
| Left | 5.3 ± 0.6 | 5.2 ± 0.6 | 5.2 ± 0.6 | -2.8 [-6.2, 0.7] | -1.7 [-5.2, 1.8] | 3.6 [2.4, 6.6] | 3.4 [2.3, 6.5] | 0.94 [0.74, 0.98] | 0.93 [0.71, 0.99] |
| Right | 5.3 ± 0.5 | 5.1 ± 0.6 | 5.1 ± 0.6 | -3.6 [-6.3, -0.9] | -0.9 [-3.9, 2.3] | 3.5 [2.5, 5.8] | 3.6 [2.6, 6.2] | 0.93 [0.79, 0.98] | 0.94 [0.80, 0.98] |
| Peak deceleration (m/s$^2$) | | | | | | | | | |
| Left | -2.6 ± 0.3 | -2.5 ± 0.4 | -2.4 ± 0.3 | -1.3 [-8.4, 6.4 | -7.8 [-12.0, -3.5] | 9.5 [6.9, 16.2] | 5.4 [3.8, 9.4] | 0.57 [0.07, 0.84] | 0.86 [0.59, 0.95] |
| Right | -2.6 ± 0.3 | -2.5 ± 0.3 | -2.4 ± 0.2 | -4.0 [-7.8, 0.1] | -5.0 [-8.3, -1.5] | 5.2 [3.7, 8.6] | 4.2 [3.0, 7.2] | 0.86 [0.56, 0.95] | 0.90 [0.66, 0.97] |
| Peak acceleration (m/s$^2$) | | | | | | | | | |
| Left | 4.2 ± 0.3 | 4.0 ± 0.3 | 4.1 ± 0.4 | -3.3 [-4.7, -1.9] | -0.2 [-2.2, 1.9] | 1.8 [1.3, 2.9] | 2.3 [1.7, 4.0] | 0.96 [0.87, 0.99] | 0.94 [0.82, 0.98] |
| Right | 4.1 ± 0.3 | 4.0 ± 0.2 | 4.0 ± 0.4 | -0.8 [-2.3, 0.8] | -0.1 [-2.5, 2.3] | 1.9 [1.4, 3.2] | 2.8 [2.0, 4.9] | 0.93 [0.79, 0.98] | 0.90 [0.68, 0.97] |
| Ground contact time (ms) | | | | | | | | | |
| Left | 344.5 ± 112.8 | 310.9 ± 59.6 | 306.3 ± 74.1 | -7.0 [-16.7, 3.9] | -4.9 [-11.0, 1.6] | 14.4 [10.3, 24.7] | 7.8 [5.5, 13.7] | 0.81 [0.51, 0.94] | 0.93 [0.78, 0.98] |
| Right | 337.5 ± 69.5 | 328.6 ± 71.1 | 301.3 ± 58.3 | -2.8 [-7.6, 2.2] | -6.5 [-12.3, -0.4] | 6.4 [4.6, 10.7] | 7.5 [5.4, 13.2] | 0.94 [0.82, 0.98] | 0.91 [0.73, 0.97] |

consistency, all CVs were less than 10% (1.8 – 9.5%) except for ground contact time left leg between session 2 – 1 (14.4%). With regards to relative consistency, all ICC's were greater than 0.80 (0.81 – 0.96), except for peak deceleration on the left leg turn, between session 2 – 1 (0.57).

A comprehensive matrix examining the strength of association between all right and left leg variables for each IMU, and timing light metric can be found in Supplementary Table 1. There were no statistically significant differences observed between relative right and left leg IMU or timing light variables, therefore the pooled averages were used to examine associations between the variables. The strength of association between the pooled averages for each IMU and timing light variable are presented in the correlation matrix (Table 2). Correlations ranged from 0.04 to 0.95. With regards to total time measured with timing gates, the highest correlation and therefore biggest predictor of total time among IMU variables was found with peak acceleration ($r = 0.95$), and the lowest correlation was found with ground contact time ($r = 0.04$).

The biggest predictor for initial acceleration (split 1) and deceleration (split 2), was peak acceleration ($r = -0.61$, $r = -0.86$). Split 3, which is where the 180° turn occurs, had the strongest correlation with maximum speed ($r = -0.89$), while split 4 and 5 (reacceleration phases) had the strongest correlation with peak acceleration ($r$ = -0.71 and 0.68, respectively).

The highest correlation found among IMU variables was between peak acceleration and maximum speed ($r = 0.85$), while the lowest correlation reported was between ground contact time and maximum speed ($r = -0.10$). Ground contact time had trivial to low correlations with all IMU and timing light variables ($r$ = 0.23 to -0.44).

Table 2: Correlation matrix between IMU variables and timing light variables during a modified 5-0-5 COD test.

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1. Max speed | – | | | | | | | | |
| 2. Peak decel | 0.65* | – | | | | | | | |
| 3. Peak accel | 0.85** | 0.54 | – | | | | | | |
| 4. GCT | -0.10 | 0.24 | -0.13 | – | | | | | |
| 5. 5-0-5 split 1 | -0.57 | -0.44 | -0.61 | -0.20 | – | | | | |
| 6. 5-0-5 split 2 | -0.59 | -0.39 | -0.86** | 0.23 | 0.65* | – | | | |
| 7. 5-0-5 split 3 | -0.89** | -0.59 | -0.81** | -0.04 | 0.68* | 0.60 | – | | |
| 8. 5-0-5 split 4 | -0.69* | -0.55 | -0.71* | -0.18 | 0.33 | 0.34 | 0.53 | – | |
| 9. 5-0-5 split 5 | -0.57 | -0.50 | -0.68* | -0.44 | 0.39 | 0.82** | 0.40 | 0.27 | – |
| 10. 5-0-5 total | -0.91** | -0.64* | -0.95** | -0.04 | 0.74* | 0.79** | 0.94** | 0.64* | 0.60 |

*Note:* Correlation coefficient of 0 to 0.5 represents low correlation, 0.5 to 0.7 represents moderate correlation, 0.7 to 1.0 represents high correlation. decel = deceleration, accel = acceleration, GCT = ground contact time. * $p < 0.05$. ** $p < 0.001$.

## 4. Discussion

The aim of this study was to firstly, determine the intra-session reliability of the various IMU variables during a modified 5-0-5 COD test and secondly, determine the strength of inter-relationship between the different IMU and timing light variables. The main findings were: (1) there appeared to be no systematic change between the variables across sessions; (2) absolute consistency was acceptable for all variables, except for GCT on the left leg at the turn, between session 2 – 1 (14.4%) and all ICC's were greater than 0.80, with the exception of peak deceleration left; (3) no significant differences were observed between right and left leg variables, therefore the data was pooled to determine the strength of interrelationships; (4) the biggest predictor for total time measured with timing gates was peak acceleration (*r* = 0.95); and (5) Ground contact time had trivial to low correlations with all IMU and timing light variables (*r* = 0.04 to 0.44). These key findings may be of importance to coaches and practitioners when considering how to assess COD performance for court-sport athletes.

To the authors knowledge, this is the first study to look at the reliability of firstly an insole IMU, as well as these specific variables during a modified 5-0-5 COD test. All variables were found to have good to excellent relative consistency (ICC = 0.81 to 0.96), except for peak deceleration on the left turn between session 2 – 1, which had moderate relative consistency (ICC = 0.57). In terms of absolute consistency, all variables had CV's less than 10%, with the exception of ground contact time left (CV = 14.5%). Previously, Balloch and colleagues (2020) investigated the reliability of trunk-mounted IMUs to measure COD angles ranging from 45 – 180°, reporting similar reliability (CV = 1.3 – 4.2%). Barreira and colleagues (2017) also investigated the use of a trunk-mounted IMU, however they were looking specifically at the reliability of tracking player load, during a COD task. They reported good to excellent reliability for Player Load (ICC = 0.83 – 0.95) and Player Load per minute (ICC = 0.80 – 0.92), which were similar to the results reported in the current study. Lastly, there was very little systematic bias between sessions in the current study, however it needs to be noted that the participants of this study were elite level athletes that performed the modified 5-0-5 COD test on a regular basis and did not require any familiarisation.

With regards to the strength of association, it is first important to compare the IMU variables against timing light variables, specifically total time, which is currently the most common piece of equipment and metric used to measure 5-0-5 COD performance (Ryan et al., 2022b). This comparison will provide insight into whether foot-mounted IMUs provide additional diagnostic information. Total time, measured with timing gates, had the highest correlation with peak acceleration (*r* = -0.95) explaining 90.3% of total time, which intuitively makes sense, as a majority of the modified 5-0-5 COD test is spent accelerating, firstly from the start point, and secondly out of the 180° turn. In other words, peak acceleration, measured with the IMU, appears to be the greatest predictor for total time during the modified 5-0-5 COD test. To the authors knowledge, no previous research has investigated the relationship between timing light variables and IMU variables. However, Jones and colleagues (2009) previously investigated the correlation between the traditional 5-0-5 COD test and several other performance tests. The largest predictor for 5-0-5 time was sprint speed (*r* = 0.77), followed by eccentric flexor strength (*r* = 0.63). Eccentric flexor strength is thought important for decelerative ability and interestingly, had a similar relationship with total time, as seen in the current study with peak deceleration and total time (*r* = 0.64). Conversely, the lowest correlation reported for the total time measure, was with GCT (*r* = 0.04), explaining only 0.16% of total time. This is to be expected, as the GCT variable is only providing a small snapshot of what is occurring at the foot at the time of the 180° turn, whereas total time is providing a metric that represents the entirety of the test.

Previous research has determined the strength of association between the timing light phases (Ryan et al., 2021), however to the authors knowledge, there is currently no research that has determined the strength of association between timing light phases and IMU variables. Several interesting observations were made in the current study with regards to the strength of association between timing light phases and IMU variables. Firstly, split 1 which can be defined as the initial acceleration had the strongest correlation with peak acceleration (*r* = 0.61), explaining 37.0% of the shared variance. This is a moderate correlation, and the shared variance was below 50%, indicating that these metrics are relatively independent of one another. Secondly, peak acceleration also had the largest correlation with split 2 (*r* = 0.86) explaining 74% of this split, which would be expected, as athletes are likely to be hitting their peak acceleration between split 1 and 2. Thirdly, split 3 has been previously identified as the 180° turn split (Ryan et al., 2021), and one of the highest correlations between split times and IMU variables was reported between split 3 and maximum speed (*r* = 0.89), explaining 79% of the shared variance. These findings suggest one of two things. First, the higher the max speed reached during the test, the faster the time of the 180° turn split. Second, the faster the 180° turn split, the faster max speed reached during the test. The latter is likely the case, as athletes should be reaching their maximum speed during the end of the reacceleration phase of the test, and if an athlete performs the 180° turn well, this should set them up for a better reacceleration. When taking into consideration the population used in this study (elite athletes), this makes sense, as those reaching higher max speeds are likely having faster entry velocities coming into the turn and have the ability to decelerate quickly and effectively coming into the turn. It is also likely that these athletes have well developed reactive strength to push out of the turn and therefore also have fast exit velocities (McLeod & James, 2018).

With regards to the relationship between the four IMU variables reported, peak acceleration and maximum speed had the strongest correlation (*r* = 0.85), with peak acceleration explaining 72.3% of maximum speed. This intuitively makes sense, as those athletes with greater peak acceleration, will usually reach the higher maximum speeds during the test. Conversely, GCT at the turn and maximum speed had the weakest relationship (*r* = -0.10), explaining only 1% of one another. This was to be expected, as GCT variable is measured at the time of the turn when the GCT will be the longest throughout the entire test, however the athlete has more steps to reaccelerate after the turn and achieve maximum speed (Dos' Santos et al., 2020). If average GCT was explored during the different phases such as acceleration, a stronger correlation would likely be observed. These results indicate that GCT is providing additional diagnostic information, as it had a weak relationship between both IMU variables and timing light variables ($r$ = -0.44 to 0.23). It seems that GCT is an important variable to track with regards to COD performance, as it is thought that faster GCT result in better COD performance (Dos' Santos et al., 2020). This diagnostic information could provide practitioners with information regarding an athlete's reactive abilities when pushing out of the turn and inform further programming to minimise GCT and enhance an athlete's 180° turning ability. Peak deceleration also had moderate to low correlations with other IMU variables and timing light metrics ($r$ = -0.64 to 0.59), suggesting that this IMU variable is providing additional diagnostic information that can be used by coaches and practitioners to further refine their exercise prescription.

Authors have detailed the importance of linear speed, deceleration, and reacceleration during COD manoeuvres (Ryan et al., 2022a; Sheppard & Young, 2006). Specifically with the 5-0-5 COD test beginning with acceleration, then deceleration to a complete stop and reacceleration into the new direction (Clarke et al., 2022), it would seem important to monitor these variables. The IMU insoles used in this study were found to provide a reliable way to measure acceleration, maximum speed, deceleration, and ground contact time during a modified 5-0-5 COD test. Though some high correlations were reported between timing gate splits and IMU variables, it appears that most of the IMU variables are relatively independent ($R^2 < 50\%$), therefore can be used in addition to timing gates, to increase the diagnostic value of the modified 5-0-5 COD test.

### *4.1. Conclusion, limitations, and practical applications*

It appears that an IMU mounted on the insole of a shoe can be used to reliably measure peak acceleration, peak deceleration, max speed, and ground contact time during a modified 5-0-5 COD test. The information reported in this study provides coaches and practitioners with valuable information, for example, peak acceleration seems the biggest predictor for total 5-0-5 COD time. This information can help coaches become more specific with their programming. Additionally, a majority of the IMU variables are relatively independent to the timing light variables, therefore providing a rationale for the inclusion of this IMU insole to provide additional diagnostic information during a modified 5-0-5 COD test. The results of this study need to be interpreted with caution, as this study used elite level netball athletes, and therefore the results may be different for athletes of a different level, sport, or gender. Based off the results of the current study, it appears that use of the IMU insole can advance the diagnostic ability of the protocol for the modified 5-0-5 COD test. This advancement will enable coaches and practitioners to reliably track different metrics deemed important for COD performance. Additionally, it may help coaches identify areas of strengths and weakness for their athletes. These insights could assist with improving COD performance; however, such hypothesis needs to be validated using longitudinal designs.

## Conflict of Interest

The authors declare no conflict of interests.

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## Supplemental materials

Supplementary Table 1: Correlation matrix between IMU variables and timing light variables for left and right leg turns during a modified 5-0-5 COD test.

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Max speed left | – | | | | | | | | | | | | | | | | | | |
| 2. Peak decel left | -0.71* | – | | | | | | | | | | | | | | | | | |
| 3. Peak accel left | 0.82** | -0.48 | – | | | | | | | | | | | | | | | | |
| 4. GCT left | -0.01 | -0.25 | -0.16 | – | | | | | | | | | | | | | | | |
| 5. Max speed right | 0.98** | -0.72* | 0.81** | -0.03 | – | | | | | | | | | | | | | | |
| 6. Peak decel right | -0.48 | 0.79** | -0.44 | -0.17 | -0.52 | – | | | | | | | | | | | | | |
| 7. Peak accel right | 0.84** | -0.55 | 0.97** | -0.02 | 0.86** | -0.56 | – | | | | | | | | | | | | |
| 8. GCT right | -0.21 | -0.13 | -0.26 | 0.81** | -0.13 | -0.30 | -0.04 | – | | | | | | | | | | | |
| 9. Left 5-0-5 split 1 | -0.50 | 0.32 | -0.56 | 0.27 | -0.59 | 0.43 | -0.67* | -0.06 | – | | | | | | | | | | |
| 10. Left 5-0-5 split 2 | -0.59 | 0.28 | -0.89** | 0.35 | -0.60 | 0.34 | -0.86** | 0.27 | 0.71* | – | | | | | | | | | |
| 11. Left 5-0-5 split 3 | -0.76* | 0.63 | -0.67* | -0.11 | -0.79** | 0.65* | -0.78** | -0.12 | 0.73* | 0.60 | – | | | | | | | | |
| 12. Left 5-0-5 split 4 | -0.78** | 0.44 | -0.79** | 0.05 | -0.71* | 0.33 | -0.71* | 0.33 | 0.23 | 0.48 | 0.42 | – | | | | | | | |
| 13. Left 5-0-5 split 5 | -0.65* | 0.59 | -0.77** | 0.25 | -0.63 | 0.54 | -0.77** | 0.22 | 0.60 | 0.85** | 0.54 | 0.47 | – | | | | | | |
| 14. Left 5-0-5 total | -0.86** | 0.62 | -0.91** | 0.07 | -0.89** | 0.63 | -0.96** | 0.10 | 0.70* | 0.82** | 0.90** | 0.63* | 0.73* | – | | | | | |
| 15. Right 5-0-5 split 1 | -0.51 | 0.33 | -0.53 | -0.06 | -0.60 | 0.53 | -0.68* | -0.34 | 0.89** | 0.53 | 0.75* | 0.35 | 0.39 | 0.68 | – | | | | |
| 16. Right 5-0-5 split 2 | -0.54 | 0.34 | -0.79** | 0.28 | -0.62 | 0.41 | -0.83** | 0.05 | 0.73* | 0.89** | 0.48 | 0.38 | 0.82** | 0.72* | 0.59 | – | | | |
| 17. Right 5-0-5 split 3 | -0.90** | 0.55 | -0.78** | -0.05 | -0.92** | 0.35 | -0.83** | 0.12 | 0.53 | 0.62 | 0.84** | 0.57 | 0.52 | 0.89 | 0.53 | 0.53 | – | | |
| 18. Right 5-0-5 split 4 | -0.37 | 0.49 | -0.40 | -0.71* | -0.36 | 0.49 | -0.46 | -0.51 | 0.12 | 0.12 | 0.46 | 0.51 | 0.11 | 0.41 | 0.43 | 0.09 | 0.33 | – | |
| 19. Right 5-0-5 split 5 | -0.54 | 0.47 | -0.69* | 0.55 | -0.57 | 0.30 | -0.61 | 0.50 | 0.49 | 0.76* | 0.29 | 0.40 | 0.83** | 0.56 | 0.18 | 0.79** | 0.42 | -0.13 | – |
| 20. Right 5-0-5 total | -0.89** | 0.63 | -0.90** | -0.01 | -0.93** | 0.57 | -0.97** | 0.00 | 0.74* | 0.78** | 0.88** | 0.65* | 0.70* | 0.97** | 0.75* | 0.75* | 0.91** | 0.46 | 0.56 |

*Note:* Correlation coefficient of 0 to 0.5 represents low correlation, 0.5 to 0.7 represents moderate correlation, 0.7 to 1.0 represents high correlation. decel = deceleration, accel = acceleration, GCT = ground contact time. * $p < 0.05$. ** $p < 0.001$.