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Physiological demands of Kī-o-Rahi - indigenous team ball sport in Aotearoa, New Zealand

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ABSTRACT
Kī-o-Rahi is a unique indigenous Māori mixed-sex team ball sport played in Aotearoa, New Zealand. This is the first published study to quantify the physical demands of Kī-o-Rahi. Players (n = 17, 8 females and 9 males) wore 10-Hz Global Positioning System (GPS) and heart rate units while playing 5 games. Mean ± SD were calculated for maximum speed ($km \cdot h^{-1}$), total distance (m), running distance (≥ 7.1 $km \cdot h^{-1}$), high intensity running (≥ 16 $km \cdot h^{-1}$), and heart rate ($b \cdot min^{-1}$). On average, players travelled 825 ± 169 m, ran 479 ± 130 m, covered 76 ± 56 m at high intensity, and reached maximal speeds of 22 ± 3 $km \cdot h^{-1}$, with a heart rate of 152 ± 21($b \cdot min^{-1}$) per game. Males covered 16.7 ± 11.3 m more total distance per min, ran 9.8 ± 9.3 m further per min, and covered 5.6 ± 3.8 m more high intensity distance per min than female players ($p \leq 0.05$). Distances in games 4 and 5 were significantly decreased (25% to 70%, $p < 0.05$) compared to game 1, which suggests accumulated fatigue throughout the day. Coaches should consider recovery and nutritional strategies between games and training should focus on developing aerobic capacity and explosive speed due to the physically demanding nature of competition. Future research should determine game movement patterns, investigate recovery strategies, possible gender differences, fitness levels, and/or team tactics.

1. Introduction

Kī-o-Rahi is a unique fast-paced indigenous Māori mixed-sex ball game played on a circular field (Brown, 2010). As a tākaro Māori, Māori game, Kī-o-Rahi all but disappeared in Aotearoa, New Zealand due to European colonization, as the sport was seen as a barrier to the uptake of Christianity by the indigenous Māori people of Aotearoa New Zealand (Brown, 2010; Palmer et al., 2009). Owing to ongoing effects of colonization, there is minimal research on the sport, as participation in the tākaro was not encouraged and therefore only played by Māori people in informal settings. However, since the 1970s, the tākaro has been growing in popularity throughout Aotearoa New Zealand and a national secondary school Kī-o-Rahi competition started in 2010 (Harris, 2016; Terruhn, 2019). In addition to the multiple health benefits of team sport participation (Janssen et al., 2010), a unique aspect of Kī-o-Rahi is that it also provides an opportunity for players to develop an understanding of Māori culture while participating in the tākaro, which is increasingly important as Aotearoa, New Zealand progresses towards biculturalism (Palmer et al., 2009; Harris, 2016).

Biculturalism within the context of Aotearoa, New Zealand, refers totangata whenua, the indigenous Māori population, tangata tiriti, New Zealanders, living and respecting each other (Hayward and Wheen, 2012), where these two groups respect each other's values, beliefs, rights, and resources (Durie, 2003; Linnér et al., 2022). Key to understanding this partnership is to engage with Te Tiriti o Waitangi (Durie, 2003), the founding document of Aotearoa, New Zealand's current society that provides a guide for a positive bicultural future for all citizens. Fundamentally, Te

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Tiriti o Waitangi is about social justice, making it relevant to all people living in the communities of Aotearoa, New Zealand, as well as an exemplar for all other nations that wish to work meaningfully with their indigenous populations (Harris, 2016; Ministry of Health 2020). Te Tiriti o Waitangi provides a platform for recognizing Māori needs and aspirations, ensuring Māori people can enjoy equal and equitable opportunities. However, due to the consequences of colonization, Māori people face persistent inequity and typically have poorer health outcomes compared to other groups in Aotearoa, New Zealand (Durie 2003; Linnér et al., 2022). Consequently, there has been minimal research on the sport.

Kī-o-Rahi is a Māori ball sport that encompasses the Māori world view; therefore, the game can be a vehicle for intergenerational transmission of traditional practices, values, traditions, protocols, and understanding of the world (Palmer et al., 2009). Kī-o-Rahi is based on the journey of Rahi, who has been attributed with the creation of Kī-o-Rahi. The game is based on Rahi's pursuit of a patupaiarehe, spiritual being, who had kidnapped his wife Te Ara and the conflict resolution that occurred after his wife was returned, which led to the creation of the game (Palmer et al., 2009).

Global Positioning System (GPS) is a satellite-based technology that tracks movements over time and is widely used in team sports to measure player positions and speed (Coughlan et al., 2011; Cummins, 2013). The technology allows monitoring of activity intensity, and the movement demands placed on players during training and games (Cummins, 2013; Hodun et al., 2016). Data collected from GPS in games, such as running and sprinting distances, can then be utilized to develop sport-specific training programs for team sports and to aid in the rehabilitation of players returning from injury (Olsen et al., 2023). In Aotearoa, New Zealand, GPS technology has been used extensively in research on team sports such as rugby union and rugby sevens to quantify the physical demands of these sports (Ross et al., 2015; King et al., 2018; Busbridge et al., 2022; Takamori et al., 2022; Olsen et al., 2023). To date, there has been no research to quantify the physical demands of Kī-o-Rahi. The aim of this study was to determine the physiological demands of Kī-o-Rahi. Quantifying the physical demands of Kī-o-Rahi could assist trainers and coaches to plan and implement programs that elicit physiological adaptations specific to the mixed-sex team ball sport. Additionally, the study also addresses inequities in sport science research in Aotearoa, New Zealand, where research has predominately focused on non-indigenous male sports introduced during colonization.

2. Methods

2.1. The game

Kī-o-Rahi is played on a field that consists of three concentric circles or playing zones (Figure 1). The playing zones are intersected by a pathway called the te ara (UNICEF UK, n.d.). At the center of the inner zone (te pāwero) (4-m radius) is the tupu (wairua) or target (UNICEF UK, n.d.). The middle circle, te roto, has a radius of 11 m, and the outer circle, te ao, has a radius of 21 m (Figure 1). Seven posts, pou, (indicated as red dots in Figure 1) are evenly spaced around the outer circle (te ao) area (UNICEF UK, n.d.). Two teams of seven players are on the field during a 14-min game (7-min halves, separated by a 1-min break). Rolling substitutions can be made throughout a game. One team is the kīoma and can score by touching posts in the outer circle (te ao) and then running through the middle circle (te roto) touching down in the inner circle (te pāwero) (UNICEF UK, n.d.). If a kīoma player is tagged, they have three seconds to pass the ball to a teammate or it goes to the other team, who are named the taniwha (UNICEF UK, n.d.). The Taniwha team scores by throwing from the middle circle (te roto) and hitting the tupu or target in the center of the inner circle (te pāwero, which is protected by goalies similar to soccer) (Figure 1). The game is played in quarters or halves, and at the end of each quarter or half, the team positions changes from Kīoma to Taniwha. A full description of the game has been previously published (UNICEF UK, n.d.).

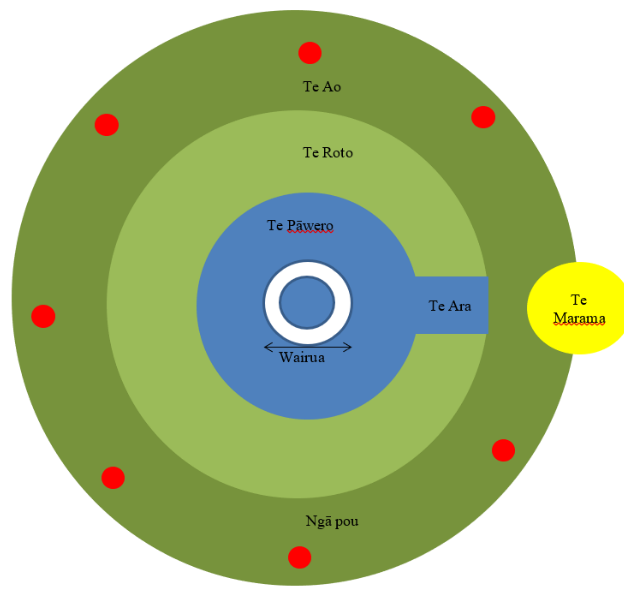

Figure 1: Te papa tākaro Kī-o-Rahi: Kī-o-Rahi field layout.

2.2. Participants

Heart rate and GPS data were collected in the first five of seven Kī-o-Rahi games on Day 1 of a two-day National Secondary Schools competition held in Waitangi in April 2021. Participants were all the players in one team of 17 players (8 females; age 16 ± 1 y, height 163 ± 6 cm, body mass 60 ± 7 kg; 9 males; age 16 ± 1 y, height 177 ± 6 cm, body mass 74 ± 6 kg). In total, there were 38 GPS files recorded during the five games. One file represents a player who played for 7-min or more (i.e., at least half a game). Informed consent was gained from all players and ethical approval (#1881) was attained from an Institutional Ethics Board. Players were informed of the benefits and risks of participation and signed written consent before participating.

2.3. Procedure

Players wore a 10-Hz GPS unit (VX Sport™, Lower Hutt, Aotearoa, New Zealand) for the duration of each game, which have been found to produce valid and reliable measurements in team sport movements (Crang et al., 2021). The unit was secured in a pocket in a VX Sport™ vest in the region of the upper thoracic spine. The GPS and HR units were turned on approximately 5-min before the start of a game and turned off at the end of a game. Data were extracted from the GPS units using VX Sport™ software. Heart rate data were captured using Polar V800 downloadable heart rate monitors (60-Hz) (Polar Electro Oy, Kempele, Finland), which were fitted for players prior to warm-up, data was downloaded after games using the Polar FlowSync software. Substitutions were also manually recorded to enable heart rate and GPS data to be trimmed to include only playing time data in the analysis. The variables collected in the research were maximum speed (km·h^{-1}), total distance (m), running distance (≥ 7.1 km·h-^{1}), high intensity running (≥ 16 km·h^{-1}), and heart rate (b·min^{-1}). Relative distance measurements (m·min^{-1}) were also calculated by dividing the GPS distance measurements by the minutes played per game

2.4. Statistical Approach

Player data were classified into positional groups to indicate if a participant played exclusively in the outer circle (te ao) and middle circle (te roto) (Figure. 1) or in both te ao and te pāwero (goalie position), the outer and inner circles. On average, there were 18 substitutions per game. The GPS files were only used from players who had played for 7-min or more (i.e., equivalent to playing the duration of one half). This approach is standard practice in GPS research on other sports, as it enables the workload of a player involved in a substantial amount of the game to be determined (Olsen et al., 2023). In total there were 38 GPS data files from players who played 7-min or more. The data was visually checked for outliers (any data point over 3 SD from the mean) and inaccurate data by investigating the distribution and probability plots. In addition, normality of the data was confirmed with a Shapiro-Wilk test.

Data are presented as the mean ± SD for maximum speed (km·h^{-1}), total distance (m), running distance (≥ 7.1 km·h^{-1}), and high intensity running (≥ 16 km·h^{-1}). The running distance and high intensity running zones were based on a review by Hodun et al. (2016) of female team sports as there are female and male participants in the study. Mean ± SD data were also calculated for heart rate measurements (b·min^{-1}) in each game. Changes in the mean and SD representing the between-and within-subject variability were estimated using a mixed modeling procedure (Proc Mixed) in the Statistical Analysis System (Version 9.3, SAS Institute, Cary, NC). The difference in the mean GPS variables between groups (player positions, sex) and over time (games 1 to 5) using a repeated measures univariate ANOVA's in the Statistical Analysis System using the Proc Mixed procedure (version 9.4; SAS Institute, Cary, NC). We also calculated the effect size statistics (Cohen's *d*). The magnitude of the effect size (ES) was interpreted using descriptors proposed by Hopkins et al. (i.e., 0.0-0.19 trivial, 0.20-0.59 small, 0.6-1.19 moderate, 1.2-1.99 large, and 2.0-3.99 very large; Hopkins 2009).

3. Results

3.1. GPS measures

Table 1 and Table 2 shows non-significant differences were evident (0 m to 38 m, $p > 0.05$) in absolute and relative (m·min^{-1}) measures for total distance, running, and high-intensity running distance measures between players in the outer circle (te ao) and middle circle (te roto), and those in the outer circle (te ao) and the inner circle (te Pāwero). Effect sizes (ES) ranged from 0.02 to 0.51. There were also no significant differences in maximal speed (22.7 ± 3.6 km·h^{-1} and 21.6 ± 1. km·h^{-1}) and time played (9.5 ± 1.8 min and 9.0 ± 2.0 min,~1.0 km·h^{-1}, ES = 0.37 and 0.5 min, ES = 0.26, respectively) for players in the outer circles or inner and outer circles.

Table 1: Absolute distance (m) per game in Kī-o-Rahi positions.

Positions	Total distance	Distance ≥ 7.1 km.h^{-1}	Distance ≥ 16 km.h^{-1}
All data[1]	825.1 ± 169.1	478.8 ± 129.6	75.9 ± 55.9
Outer & middle circles[2]	836.2 ± 174.8	486.2 ± 136.9	84.2 ± 59.9
Inner and outer circles[3]	797.7 ± 158.7	460.6 ± 113.7	55.6 ± 40.3

Notes: Data = mean ± SD. [1]Outer circle + inner & outer circle position data combined. [2]Outer circle (te ao) & middle circle (te roto). [3]Outer circle (te ao) & te pāwero (goalie position).

Table 2: Relative distance (m·min^{-1}) per game in Kī-o-Rahi positions.

Positions	Total distance	Distance ≥ 7.1 km.h^{-1}	Distance ≥ 16 km.h^{-1}
All data[1]	90.7 ± 19.1	53.1 ± 15.3	8.7 ± 6.3
Outer & middle circles[2]	90.8 ± 20.6	53.2 ± 16.3	9.5 ± 6.8
Inner and outer circles[3]	90.6 ± 15.4	52.9 ± 13.3	6.6 ± 4.5

Notes: Data = mean ± SD. [1]Outer circle + inner & outer circle position data combined. [2]Outer circle (te ao) & middle circle (te roto). [3]Outer circle (te ao) & te pāwero (goalie position).

Table 3: Absolute distance (m) per game for female and male players.

	Total distance	Distance ≥ 7.1 km.h^{-1}	Distance ≥ 16 km.h^{-1}
Female	791.3 ± 199.7	457.4 ± 141.7	52.2 ± 28.2
Male	855.5 ± 133.8	498.1 ± 118.1	97.2 ± 66.2**

Notes: Data = mean ± SD. $^{**}p \leq 0.01$.

During the games, male and female players covered similar absolute distance (855.5 m and 791.3 m, respectively, $p = 0.25$, ES = 0.37) and running distance (≥ 7.1 km·h^{-1}) (498.1 m and 457 m, respectively, $p = 0.3$, ES = 0.31). However, when expressed as relative measures, male players typically covered more total distance (16.7 ± 11.3 m·min^{-1}, mean ± 95% CI, $p = 0.005$, ES = 0.77) and greater distance (9.8 ± 9.3 m·min^{-1}, $p = 0.05$, ES = 0.64) compared to female players (Table 3 and 4). Males also covered more distance in both absolute (44.9 ± 33.5 m, $p = 0.01$, ES = 0.80) and relative measures (5.6 ± 3.8 m, $p = 0.005$, ES = 0.88) at high-intensity (≥ 16 km·h^{-1}) than female players. Additionally, male players had significantly higher maximum running speeds compared to female players (23.8 ± 3.0 km·h^{-1} vs. 20.8 ± 2.6 km·h^{-1} respectively, p = 0.003, ES = 0.92), but typically played for 1-min less per game than female players (9.9 ± 2.2 min vs. 8.9 ± 1.3 min, p = 0.07, ES = 0.57).

Table 4: Relative distance (m·min^{-1}) per game for female and male players.

	Total distance	Distance ≥ 7.1 km.h^{-1}	Distance ≥ 16 km.h^{-1}
Female	81.9 ± 19.1	47.9 ± 15.4	5.7 ± 3.1
Male	98.7 ± 15.6**	57.8 ± 14.0*	11.3 ± 7.4**

Notes: Data = mean ± SD. *$p \leq 0.05$. **$p \leq 0.01$.

Figures 2 and 3 show that the overall absolute and relative distances typically decreased with the number of games played during the tournament. The comparison of the absolute and relative distances in game 1 and 2 with games 4 onwards showed that there was a significant reduction in distance covered in the latter games ($p < 0.05$) with ES ranging from 0.71 to 2.47 between game 1 and games 4 or 5. Game 4 relative distance measures were also significantly lower than game 3 distances ($p < 0.05$, Figure 3) and game 2 had lower high running distances ($p < 0.05$, Figure 2 and 3) than game 1. There was minimal difference (2% to 3% $p \geq 0.05$) in the average time played and the average maximal speed between the games.

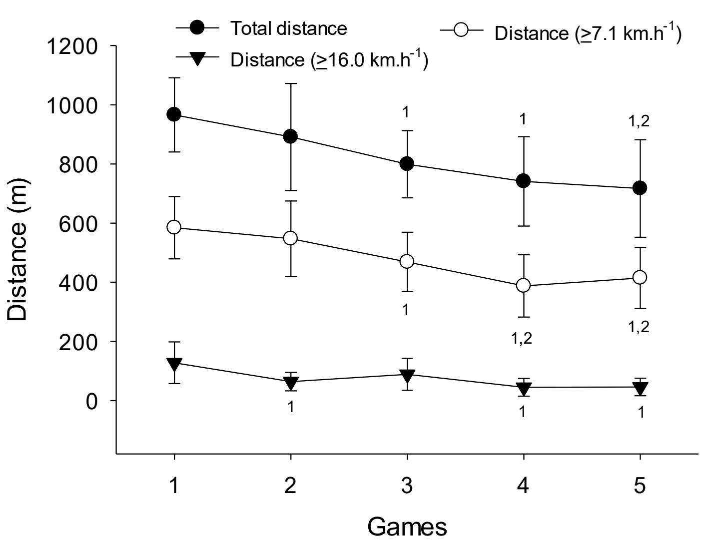

Figure 2: Absolute distances (m) in five Kī-o-Rahi games. *Notes:* [1]Significant difference between this game vs. Game 1, [2]Significant difference between this game vs. Game 2.

3.2. Heart rate

There were no significant ($p > 0.05$) differences between player heart rates when they played in the outer or inner-and-outer zones (151 ± 20 vs. 154 ± 22 b·min^{-1}, mean ± SD) or between players in the outer zones and those in the inner zone guarding the target or tupu (149 ± 19 vs 165 ± 33 b·min^{-1}, $p > 0.05$). In contrast, there were significant differences between female and male players, with males having higher heart rates during games (169 ± 22 vs 139 ± 7 b·min^{-1}, p = 0.02, ES = 1.9), and when they played in the outer zones (168 ± 18 vs 138 ± 7 b·min^{-1}, p = 0.01, ES = 1.7), and in the inner-and-outer zones (170 ± 22 vs 141 ± 12 b·min^{-1}, p = 0.04, ES = 1.3) compared to female players.

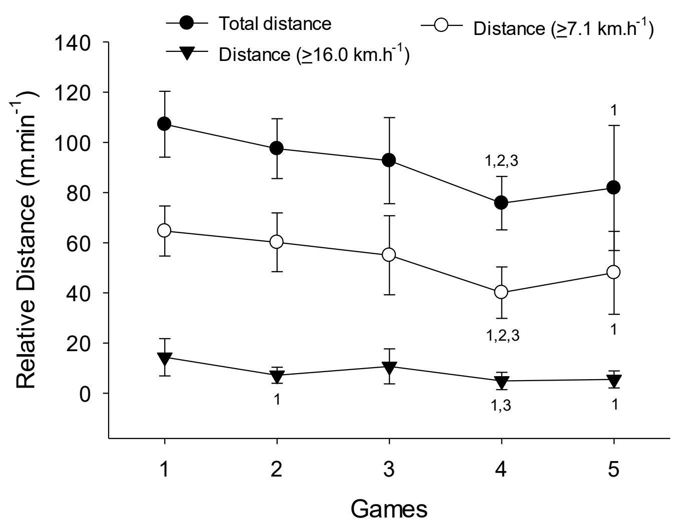

Figure 3: Relative distances (m.min-1) in five Kī-o-Rahi games. *Notes:* [1]Significant difference between this game vs. Game 1. [2]Significant difference between this game vs. Game 2. [3]Significant difference between this game vs. Game 3.

4. Discussion

Kī-o-Rahi is an indigenous mixed-sex team ball sport played in Aotearoa, New Zealand based on the figure of Rahi. Prior to this study, no research has been published on the physical demands of this sport. The absolute total distances covered by Kī-o-Rahi players were lower than distances covered by rugby sevens players in junior, regional, and international games (825 m vs. 916 m to 2486 m) (Ross et al. 2015), which are of a similar duration as Kī-o-Rahi games. Absolute high intensity running distances (76 m at ≥ 16 km·h^{-1}) for Kī-o-Rahi players were also considerably less than those observed in secondary school representative rugby sevens team (~250 m at >18 km·h^{-1}) at an under 15 and under 17 national sevens tournament (Wintershoven et al. 2023). In contrast, average relative total distances for Kī-o-Rahi players were within the range observed for sevens players in junior, regional, and international competition (91 m·min^{-1} vs. 79 m·min^{-1} to 121 m·min^{-1}) (Ross et al. 2015). Relative measures are possibly more valid for comparisons between datasets, as they account for differences in time played in different positions and competitions (Olsen et al. 2023). Nevertheless, the distances covered performing high-intensity running in Kī-o-Rahi were approximately half that observed in sevens rugby for relative or absolute measures (Ross et al. 2015). The lower values could be due to the playing area in Kī-o-Rahi being 1521 m^2, which is less than a quarter of a standard rugby field (7000 m^2) alongside players' movement being restricted by designated zones dependent on position. This may also account for the lower maximal speeds observed in Kī-o-Rahi (22 km·h^{-1}), which were at the lower end of the range of the maximal speeds (21 km·h^{-1} to 31 km·h^{-1}) reported in a review of elite rugby sevens players in junior and senior competitions (age range under-18 to 32 years) (Ball et al. 2019). The reduced area and circular nature of the Kī-o-Rahi playing field may limit high-intensity running and maximal speeds compared to those that could be more readily achieved without stopping or changing direction on a longer rectangular field in rugby sevens.

A unique aspect of Kī-o-Rahi is that it is one of the few competitive team ball sports where female and male players play together. There were no significant differences between female and male players for the absolute total distance and absolute running (≥ 7.1 km·h^{-1}) distance covered in Kī-o-Rahi games. However, male players ran approximately twice as much distance at a high intensity (≥ 16 km·h^{-1}) when measures were expressed in relative terms (m·min^{-1}), and male players typically covered significantly more distance per minute at all speeds and reached higher maximal speeds. Ball et al. (2019) also found that there were typically no significant differences for the absolute distances between male and female players in junior, regional, or international rugby sevens competition. However, when data were expressed as relative distances (m·min^{-1}) there was a tendency for male players to cover significantly more distance and at higher speeds (Ball et al. 2019). Nevertheless, as indicated previously, a unique aspect of Kī-o-Rahi is that female and male participants play on the same team, whereas in rugby sevens there are separate women's and men's competitions. Additionally, female participants in our study typically played a minute longer on average than male players. This may represent a strategy where males predominantly play in the outer zones and females in the inner zones. Knutson and McAndrew (2016) found women were not as actively involved in games when playing on mixed-sex teams. For example, video analysis of mixed-sex elite ultimate games found male players received approximately 2.5 times more passes than female players (Knutson & McAndrew 2016). According to Knutson and McAndrew, the difference may reflect gender bias and/or indicate a team strategy to pass to male players if they are the better players. However, the authors acknowledge that assuming a gender bias in Kī-o-Rahi is speculative, and more research is needed with a larger sample of teams to determine if sex-specific playing and coaching strategies are used in Kī-o-Rahi games.

Overall absolute and relative distances typically decreased with the number of games played during the tournament. For example, total, running, and high intensity running distances were lower in the last two games compared to the first two games of the tournament, whereas there was minimal difference in the average time played and the average maximal speed in all games analysed (games 1–5). It is difficult to make comparisons with data from sevens rugby tournaments, as players typically participate in two games per day. In contrast, the Kī-o-Rahi players in our study played in seven games on the same day, of which the first five games were analysed. On average, Kī-o-Rahi player heart rates ranged from 139 b·min^{-1} to 169 b·min^{-1}, and they covered 791 m to 856 m per game depending on sex and position. If a player covered a similar distance at this exercise intensity within a small circular playing area in seven games, it is likely that considerable fatigue would occur during the competition. Rugby sevens research has found that considerable fatigue, muscle damage and soreness occur across a 2-day tournament (Clarke et al. 2015; Conte et al. 2021). Based on our findings, more research is needed to examine the loading experienced by players during Kī-o-Rahi, such as the number of accelerations and decelerations during games, and to determine the potential level of fatigue, muscle soreness, and damage over a tournament. Additionally, performance analysis of the movement patterns in the game will also enable more specific training programs to be developed for players to prepare them for Kī-o-Rahi tournaments. The authors also advise, although all players in a squad played in each game, the comparison of GPS measures from Games 1-5 may lack validity as it is not a comparison of individual players across games, as not all players included in the dataset played seven or more minutes per game. We also cannot discount that differences could be due to pacing or coaching strategies in games. Nevertheless, the authors believe that this data is useful as it provides a preliminary examination of potential fatigue across a series of Kī-o-Rahi games.

A limitation of this study is that we only examined 1 team out of the 32 teams that competed in a national competition; therefore, findings may lack transferability due to the small number of participants and using a convenience sample. The authors also acknowledge that the GPS measures used may not provide a complete picture of the physical loading of the sport. Consequently, future research in this area could consider including a larger number of teams, analyzing training and game loads for acceleration and deceleration measures, the nature and incidence of injuries, and using video analysis to quantify key performance indicators and tactics in Kī-o-Rahi. This information would be valuable for coaches and trainers in the implementation of strategies in games and preparing Kī-o-Rahi players for the specific demands of competition.

The findings of the study provide useful data about running demands in Kī-o-Rahi for the development of conditioning programs for players. Although players typically covered less distance and performed less running than in sports such rugby sevens, it is likely that Kī-o-Rahi players experienced considerable fatigue during the tournament due to playing seven games and the small playing area (i.e., less than a quarter of a standard rugby field). Based on the exercise intensity and number of games, it could be presumed that players need to have a large anaerobic and aerobic capacity, although further research with a larger sample and more teams is needed to establish this assumption. Nevertheless, a training regime similar to rugby sevens with a focus on developing explosive speed and endurance capacity would probably be advantageous for Kī-o-Rahi players, but the program should also consider the age and training history of players. Coaches and practitioners could also consider possible recovery strategies such as cooling between games, nutrition, and coaching tactics to minimize accumulated fatigue for players. Organizers may also wish to consider the potential thermal stress experienced by players as the national competition is conducted in February, one of the hottest months in Aotearoa, New Zealand.

In conclusion, Kī-o-Rahi was found to be potentially physically demanding for the high-school-aged players. If a player participated in seven games, they could cover approximately 6 km at an average heart rate of 150–170 b·min^{-1}, whilst competing in a team sport with another 13 players on a field, which is one-quarter the size of rugby field. Moreover, large decreases for all distance measures were observed in later games compared to earlier games in the tournament, which suggests that substantial fatigue accumulated over the day. The study also found differences between female and male players, with male players covering significantly more distance in all relative distance ($m \cdot min^{-1}$) measures than female players. Future research should examine further sex differences, nutrition strategies, use a larger number of teams, examine acceleration and deceleration, and utilize performance analysis to quantify movement patterns and playing strategies to enable more specific training programs to be developed in Kī-o-Rahi. Overall, the game is a fast paced, dynamic, physically demanding sport that also offers players an opportunity to engage in a mixed team sport and learn about Māori culture.

Conflict of Interest

The authors declare no conflict of interests.

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