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Exploring the effect of attackers-defenders ratio on offensive and defensive pace dynamics in U20 elite male handball game play

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Keywords: SPEED, PHYSICAL EXERTION, EXTERNAL LOAD, 7-ON-6, GAME PHASE

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Abstract

Rule modifications and amendments in handball have been periodically introduced by the International Handball Federation to develop the game, continually seeking a more attractive style of play through increased scoring, a faster pace, and fair play. A controversial rule modification allows coaches to exchange the goalkeeper for a court player, which can either rebalance or unbalance the ratio between attackers and defenders. The objective of this study was to explore how different tactical states (equal numbers, advantage/disadvantage) with or without a goalkeeper protecting the goal affect game pace, exertion and attack success. Methods: eight matches from the EHF Euro M20 2022, in which both teams were fully tracked, were analysed, resulting in a total of 982 team possessions. Tracking data were collected using a local positioning system (LPS) with inertial measurement unit (IMU) devices. Tactical variables analysed included: the number of passes completed, and number of players involved in play per possession, the number of defensive fouls, and possession durations in positional attack, slow transition, and fast transition. Kinematic variables included: Dynamic Stress Load (DSL), jerk, total distance covered, and High-Speed Running (HSR) distance. The results demonstrated that the 7-on-6 game exhibits a slower transition and requires a greater number of passes in comparison to other game play configurations. Nevertheless, it was not possible to confirm the greater effectiveness of the 7-on-6 attack in relation to the 6-on-6, likely due the small sample size and characteristics. Regarding the exertion, volume and intensity metrics, the DSL did not demonstrate differences between the various game configurations. Nevertheless, the data revealed that the jerk value was higher in both the attacking and defending phases of the 7-on-6 scenario, suggesting a higher degree of player movement. Nonetheless, future studies are needed to further explore the differences between 7-on-6 and 6-on-6 positional attacks to investigate their impact on offensive and defensive pace dynamics.

Keywords: SPEED, PHYSICAL EXERTION, EXTERNAL LOAD, 7-ON-6, GAME PHASE

Resumo

A Federação Internacional de Andebol tem introduzido periodicamente modificações e alterações nas regras do andebol para desenvolver o desporto, procurando continuamente um estilo de jogo mais atrativo através do aumento dos golos, de um ritmo mais rápido e do fair play. Uma modificação controversa da regra permite que os treinadores troquem o guarda-redes por um jogador de campo, o que pode reequilibrar ou desequilibrar a relação entre atacantes e defensores. O objetivo deste estudo foi explorar a forma como diferentes estados tácticos (igualdade numérica, vantagem/desvantagem), com ou sem um guarda-redes a proteger a baliza, afectam o ritmo de jogo, o esforço e o sucesso do ataque. Métodos: foram analisados oito jogos do EHF Euro M20 2022, em que ambas as equipas foram totalmente seguidas, resultando num total de 982 posses de bola das equipas. Os dados de localização foram recolhidos utilizando um sistema de posicionamento local (LPS) com dispositivos de unidade de medição inercial (IMU). As variáveis tácticas analisadas incluíram: o número de passes completados e o número de jogadores envolvidos por posse de bola, o número de faltas defensivas e a duração da posse de bola em ataque posicional, transição lenta e transição rápida. As variáveis cinemáticas incluíram: Carga Dinâmica de Esforço (DSL), jerk, distância total percorrida, e distância de corrida em alta velocidade. Os resultados demonstraram que o jogo 7 contra 6 apresenta uma transição mais lenta e requer um maior número de passes em comparação com outras configurações de jogo. No entanto, não foi possível confirmar a maior eficácia do ataque 7 contra 6 em relação ao 6 contra 6, provavelmente devido à pequena dimensão e caraterísticas da amostra. Relativamente às métricas de esforço, volume e intensidade, o DSL não demonstrou diferenças entre as várias configurações de jogo. No entanto, os dados revelaram que o valor do jerk foi elevado nas fases de ataque e de defesa do cenário de 7 contra 6, sugerindo um maior grau de movimento dos jogadores. No entanto, são necessários estudos futuros para explorar melhor as diferenças entre os ataques posicionais 7 contra 6 e 6 contra 6, para investigar o seu impacto na dinâmica do ritmo ofensivo e defensivo.

Abbreviations

CIFI2D - Centro de Investigação, Formação, Inovação e Intervenção no Desporto

DSL – Dynamic Stress Load

EHF – European Handball Federation

FADEUP – Faculdade de Desporto da Universidade do Porto

***g*/s** – standard gravities per second

GK – Goalkeeper

GPS - Global positioning system

HSR – High-Speed Running

IHF – International Handball Federation

IMU – Inertial measurement unit

IPCB – Instituto Politécnico de Castelo Branco

LPS – Local positioning system

m – meter

min - minute

s – second

TMA – Time-motion analysis

UP – Universidade do Porto

UTAD – Universidade de Trás-os-Montes e Alto Douro

UWB – ultra-wideband

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1. Introduction

Since its creation in the 1920s in Berlin, the handball game (7- a side version or Olympic handball) has undergone constant evolution, both in technical and strategic terms (Juan Lorenzo Antón, 2010). Since the sport's inception, research has been conducted with the objective of promoting technical and tactical advancements. One notable example is the research conducted in the 1920s, which sought to observe the physiological capabilities of goalkeepers (GK) in defending a handball (IHF, 2015). Originally a slower-paced sport, modern handball is characterised by fast, intermittent, high-speed play that requires not only physical skill but also a deep tactical understanding (Karcher & Buchheit, 2014).

The game physical and strategical-tactical transformation is largely the result of a series of rule changes that have been implemented over the years to make the game more attractive, fast paced and competitive. One of the main changes that contributed to this increase in the speed of the game was the introduction of the quick reposition rule (after a team have conceded a goal), which allows for an almost immediate transition from defence to attack after a goal, without having to wait the scoring team to be positioned in their half-court. This change forced the scoring team to fast return to defence to protect the goal and avoid being in numerical inferiority. Also the created the opportunity to evolve more the goalkeepers in the attacking game, as they can be very important in fast sending the ball to the middle line to perform a fast attack after suffering a goal, the so called quick throw-off (IHF, 2015). The goalkeepers, traditionally seen as a reactive defender, has come to play an essential role in fast defence-attack transition.

The 2016 rule changes, which allowed the goalkeepers to be replaced by a court player without the need for different jersey identification, brought a new strategical-tactical dimension to handball. By allowing teams to play with seven court players in the attack, this change created new game play opportunities, but also lead to significant challenges. Although these rule changes resulted from technical ideas discussed at the IHF Forum in Denmark in 2014, which involved

the collaboration and consensus of several international expert coaches (IHF, 2016b), they have been a source of ongoing discussion and disagreement among coaches.

The 2016 rule, which allowed the goalkeepers to be replaced by a line player without the need for different identification, brought a new tactical dimension to handball. By allowing teams to play with seven court players in offensive situations, this change created opportunities, but also imposed significant challenges. Although this change came about because of ideas that emerged during the International Handball Federation (IHF) FORUM in Denmark in 2014, which saw the co-operation of several well-regarded international coaches (IHF, 2016b). The IHF has produced numerous technical articles, reports, magazines and opinion pieces to justify the rule change. For example, IHF published records of past championships, such as the 1963 European Championship and the 1966 German Championship, where teams decided to use the goalkeepers as a court player in the final offensive actions at the end of the match. (IHF, 2015).

Additionally, the IHF has produced several technical statistical game analyses on how teams implemented and exploited the rule changes that led to the emergence of the 7-on-6 positional attacking game, along with its impact on performance. Although the deployment of a seventh court player has become a more common strategy, as evidenced by (Späte, 2021), who cites the first successful instance of this tactic being employed by the Norwegian women's team, data from the 2021 World Championship indicates that the efficacy of these plays remains limited. The IHF work showed that 7-on-6 attacking play , had a 10 per cent lower success rate compared to traditional positional play (such as 6-on-6), revealing the complexity and risk of this approach (Landuré et al., 2021).

Furthermore, the reduced efficacy of the attacking team when the goalkeepers is substituted to create numerical superiority is also evident in situations where one team is at a numerical disadvantage because of a two-minute suspension (Späte, 2023). In general, attacks without a goalkeeper placed in goal area were not an important differentiator within the game, since

attacks were only used in special strategy for short periods of the game. Such a strategy remains only a tactical option within the repertoire of the team's coach (Späte, 2021). The strategy of removing the goalkeepers to create a numerical advantage in attack has been employed by teams when they are experiencing a deficit and are attempting to re-establish a competitive position in the game. (Maroja et al., 2020; Prudente et al., 2022). It is crucial to emphasise that the strategy of playing without the goalkeepers with the intention of creating a numerical advantage can be extremely risky, as a single mistake by the attacking team can result in a direct shot from the defending team into the unguarded goal (Gümüş & Gençoğlu, 2020a; Krahenbühl et al., 2019a).

The increased pressure on court players when they are required to play without a goalkeepers in goal, against a more active defence and passive play marking by the referee, forces teams to make quick and precise decisions, which in turn raises the level of technical and mental demands on the players (Landuré et al., 2023). As a result, contemporary handball is characterised by constant flow and rapid transitions between defence and attack, features that reinforce its position as one of the most dynamic sports in the world (Landuré et al., 2021).

Statistical data from the 2021 World Cup was also used corroborates this game play practice assumption by the Methods Commission from the IHF. The increase in the number of attacks per game and the decrease in the average time of each attack, now at an average of about 33 seconds, are clear indications of a faster, more attack-orientated game (Landuré et al., 2023).

The data from the 2021 World Cup corroborates this perception. The increase in the number of attacks per game and the decrease in the average time of each attack, now at 33.8 seconds, are clear indications of a faster, more attack-orientated game (Landuré et al., 2021). In short, the changes in handball rules over the last few years seems not only have accelerated the pace of the game, but have also redefined the role of key players, such as the goalkeeper, and brought new team strategic possibilities. Although many studies have examined the results of games and the effectiveness of new rules and tactics, there is a

lack of research focused on offensive and defensive pace dynamics as a result of these new game play possibilities.

The research examining the impact of the 7-on-6 attack has, until now, been conducted in fragmented and isolated manner, relying on video footage notational analysis, with the objective of assessing the effectiveness of this format of play in a more general sense (e.g, Flores-Rodríguez & Ramírez-Macías, 2021; Gümüş & Gençoğlu, 2020a; Krahenbühl et al., 2019a; Krahenbühl et al., 2021; Maroja et al., 2020; Musa et al., 2017). The introduction of new tracking technologies, even for use in indoor facilities, has enabled the monitoring of indoor sporting events with greater precision and convenience (Estriga et al., 2024). Consequently, we were granted access to the players' positional tracking data during the U20 European Handball Championship. This approach enabled us to integrate the positional data with notational analysis, an aspect that justifies the value of this work due to its innovative methodological nature.

The main objective is to examine the impact of different tactical states (equal numbers, advantage/disadvantage) with or without a goalkeeper protecting the goal affect game pace, exertion and attack success.

The following hypotheses were formulated:

1) The game pace and the number of passes in the 7-on-6 positional game is lower than in the 6-on-6 positional game.
2) The 7-on-6 is most used in situations of scoring disadvantage.

3) The attack effectiveness is higher in the 7-on-6 positional game compared to the 6-on-6 positional game.

4) The subsequent attack by the defending team, after facing 7 attackers (with the opposing team having an empty goal), is characterized by a greater number of fast transitions and fewer passes.

5) Physical exertion is lower in the 7-on-6 positional game compared to the 6-on-6 positional game.

2. Literature Review

2.1. The handball game and rules changes

For coaches, physical trainers, and physiotherapists, whose main purposes are to monitor fatigue, optimize physical performance, and prevent injuries, handball is becoming a much more complex sport due to all the rule changes imposed and its strategic exploitation by the coaches and players (Michalsik & Aagaard, 2015).

Handball is an Olympic sport widely practised across the world. Like other team sports, handball has undergone various rule changes over the years (Iusepolsky et al., 2022), primarily aimed at making the game safer, faster or more appealing to a broader audience (Marczinka & Gál, 2018). Going back to the foundational ideas from Bayer (1994), each sport's rules define the legal framework of each sport, established and amended by different federations, with a specific code of arbitration. These rules shape the identity of each game, dictating how to score and prevent scoring, how to handle the ball, the conduct of players in attack and defence, and establishing general authorisations and prohibitions within the game.

The rules of handball have been a topic of common discussion among coaches, technical staff, and academics. Juan Lorenzo Antón (2010) provides a brief history of handball's rules, focusing on hot topics such as the passive play rule. According to the author, this rule was introduced to speed up the game, as in the 1970s, an attack could last over three minutes when a team was outnumbered. For many years, the enforcement of this rule was largely dependent on the subjective judgement of referees until it was revised in 2016 by the IHF, as transcribed below:

> Rules 7:12: "When a tendency to passive play is recognised, the forewarning signal (hand signal no. 17) is shown. This gives the team in possession of the ball the opportunity to change its way of attacking in order to avoid losing possession. If the way of attacking does not change after the forewarning signal has been shown, the referees can whistle for passive play at any moment. If no shot on goal is taken by the attacking

team after a maximum of 6 passes, then a free throw is called against this team” (13:1a, procedure and exceptions see Clarification No. 4, section D).” (IHF, 2016a, p. 23)

In 2022, the passive play rule was altered once again by the IHF, as transcribed below.

> Rules 12. “When a tendency to passive play is recognised, the forewarning signal (hand signal no. 17) is shown. This gives the team in possession of the ball the opportunity to change its way of attacking in order to avoid losing possession. If the way of attacking does not change after the forewarning signal has been shown, the referees can whistle for passive play at any moment. If no shot on goal is taken by the attacking team after a maximum of 4 passes, then a free throw is called against this team” (13:1a, procedure and exceptions see Clarification No. 4, section D).” (IHF, 2022, p. 19)

Returning to the 1990s, game´s dynamics clearly changed with the introduction of a new rule that accelerated play. The most notable change was the implementation of the "quick throw-off", which allowed the team to restart the game immediately after conceding a goal, without waiting for the opposing team to fully retreat to their own half. This rule aimed to reduce interruptions and maintain a continuous flow of the game, making it more dynamic and spectator-friendly (Michalsik et al., 2015). This adjustment had a profound impact on the dynamics of the game’s phases, as teams began to explore new strategies for fast transitional play enabled by the rule changes, moving quickly from defence to offense and vice versa. As expected, teams developed new tactics for these quick transitions, increasing the physical demands on players as the game's pace quickened. This most likely game place change is highlighted by several authors, such as Sevim and Bilge (2007), who mentioned that the 13:1 a rule change has made handball a more high-tempo sport (commonly referred to as a high-speed game), with a greater emphasis on speed, agility, and rapid decision-making.

Another rule change that was the most polemic among the technical and coaching community, was the amend that allowed to use 7 court players (without a goalkeeper properly identified, leading to the commonly called “empty goal”, meaning that no player is positioned inside the goal area to protect the goal). However, it is still not clear why this rule was changed, some speculation emerged as this was a way to facilitate a strategy already being used by the coaches when having a less attacking player because of an exclusion (for more see IHF, 2016b).

Also Juan Lorenzo Antón (2010) conducted a technical analysis of the goalkeeper's use as a court player in situations of numerical disadvantage (as a consequence of a player’s 2-minute suspension), leaving the goal unprotected. In these scenarios, the goalkeepers were switched by a court player who wore an additional jersey of the same colour as the goalkeeper’s uniform, to fulfil the mandatory need of having a player properly identified as a goalkeeper.

According to the handball rulebook, until 2016, rule 4.1 states that a team could not have more than seven players on the court at the same time, with one player required to be being properly identified as the team goalkeepers, as transcribed below.

> Rules 4:1 “A team consists of up to 14 players. No more than 7 players may be present on the court at the same time. The remaining players are substitutes. At all times during the game, the team must have one of the players on the court designated as a goalkeeper. A player who is recognized as a goalkeeper may become a court player at any time. Similarly, a court player may become a goalkeeper at any time (see, however, 4:4 and 4:7). A team must have at least 5 players on the court at the start of the game. The number of players on a team can be increased up to 14, at any time during the game, including overtime. The game may continue even if a team is reduced to less than 5 players on the court. It is for the referees to judge whether and when the game should be permanently suspended (17:12).” (IHF, 2005, p. 19)

With the change to rule 4.1 in 2016, there was no longer an obligation to always have an identified goalkeeper on the court, so a team can attack with 7 court players. The aforementioned rule 4.1 was amended to read as follows.

> Rules 4:1 “A team consists of up to 14 players. No more than 7 players may be present on the court at the same time. The remaining players are substitutes. A player who is identified as a goalkeeper may become a court player at any time (note, however, Rule 8:5 Comment, 2nd paragraph). Similarly, a court player may become a goalkeeper at any time as long as he is identified as a goalkeeper (see, however, 4:4 and 4:7). If a team is playing without a goalkeeper, a maximum number of 7 court players are allowed to be on the playing court at the same time (see Rules 4:7, 6:1, 6:2c, 6:3, 8:7f, 14:1a). Rules 4:4-4:7 are to be applied to substitutions of a goalkeeper for a court player. A team must have at least 5 players on the court at the start of the game. The number of players on a team can be increased up to 14, at any time during the game, including overtime. The game may continue even if a team is reduced to less than 5 players on the court. It is for the referees to judge whether and when the game should be permanently suspended (17:12)”. (IHF, 2016a, p. 14)

As a summary, this rule change allowed any court player to leave the court to be substitute for the goalkeeper, at any time. This change allowed enabling more dynamic exchanges during numerical disadvantage situations or even to use numerical superiority (a team plays 7-on-6[1], plus Gk, with their goal empty [the attacking team]).

But most importantly, before this change was made, it was easy for the defending team to identify which player had to be fast substituted by the “real” goalkeeper, allowing them to adapt the defensive strategy to this condition. This means that most likely the player attacking with a goalkeeper jersey would not dare to shot and this would put him/her in a disadvantage situation to fast exchange with the real goalkeeper waiting at the bench for fast court entry. In this

[1] At some points in the text, we also use the definition 7 vs 6 to refer to attacks with a superior number of players.

context, Gümüş and Gençoğlu (2020a) who mentioned that in such situations, the additional player typically initiates the attacking play but then promptly returns to the sideline, rather than assuming the role of goalkeeper.

These changes were, still today, quite controversial among the technical/coaching community leading to several observational studies to look into its game effect, mainly focusing into game performance (winning or losing) (Iusepolsky et al., 2022; Krahenbühl et al., 2019a).

2.2. 7-on-6 Game Play Studies

Since the rule 4.1 (IHF, 2016a), allowing the 7-on-6 court players, was implemented and first used in official competitions at the Rio 2016 Olympic Games, numerous studies have been conducted to observe and assess the impact of the change. Krahenbühl et al. (2019a) conducted a study analysing the attacking play without a goalkeeper on court during the Rio 2016 Olympic Games. The study examined the final 8 matches of the competition, analysing a total of 841 attacking sequences. Of these, teams employed the additional court player 144 times, resulting in 82 goals when playing 7-on-6. The study concluded that leaving the goal empty —due to substituting the goalkeeper with a court player— provided no statistically significant advantage or disadvantage.

It was possible to compare the increase in the use of 7-on-6 through two studies, one carried out during the 2017 Men's World Cup and the 2020 Men's European Championship. In the 20 games from the 2017 championship that were analysed from the top four, 19 attacks were made using 7-on-6 from 990 attacking plays (Prudente et al., 2019). At Euro 2020, 123 positional attacks with 7-on-6 were observed in 28 matches from the top 12 teams (Prudente et al., 2022).

Also, Krahenbühl et al. (2021) investigated the occurrence and efficiency of the 7-on-6 game play based on 15 matches from the 2017 Women's World Championship. The authors analysed a total of 1.638 attacks and concluded that the use of an additional court player did not provide a performance advantage for the teams, as they conceded more counter-attacks when leaving the goal unguarded.

Regarding the same championship, Maroja et al. (2020) analyzed 16 play-off matches to examine the efficiency of using an additional court player; they found that out of 3107 offensive attacking sequences (or ball possessions), a goal was scored in 1760 situations (56.6 %). They also found that when teams were penalized with a 2-minute suspension and opted to build their attack with 6-on-6, they were more successful in final match result than when attacking with 7-on-6, even though the goal was unprotected in both situations

The 2017 World Championship also featured an analysis by Marczinka and Gál (2018), which examined the relationship between the scoring and the use of attacks with empty goal, the success of this tactical strategy application, and how opponents respond to this offensive strategy. In their analysis of 15 matches from Group C, they observed that attacks without a GK on court occurred 319 times, of which 98 were used to create a numerical superiority (7-on-6) and 194 to equalise the attack numbers after a 2-minute suspension. It is important to note that the 2016 Olympic Games and the 2017 European Championship were the first two major international tournaments to implement the new goalkeeper's rule. This likely did not give coaches sufficient time to adapt their strategies to this new game play possibilities.

Over the years, this rule 4.1 (IHF, 2016a), was introduce the usage of the 6-on-6 with empty goal has been adopted much more frequently during matches, in the context of two-minute suspensions. During the final phase of the 2019 Men's World Championship, teams in numerical disadvantage organized their attacks with empty goal in every instance of a two-minute suspension (Flores-Rodríguez & Ramírez-Macías, 2021); they observed a lower percentage of attacking success in comparison with the equal numbers (7-on-7).

Two studies analysed attacks without an on -court goalkeeper during the 2020 Men's European Championship. In one of the studies Gümüş and Gençoğlu (2020a) the effects and consequences of such attacks we analysed, observing a total of 465 goals scored during its use, alongside 199 technical errors committed while goalkeepers were on the bench, and 103 goals conceded into an empty goal. The researchers elaborated that using attacks with an empty goal tactical variation might influence whether a team wins or loses, with the advantages of this strategy outweighing the number of missed shots and technical errors (Gümüş & Gençoğlu, 2020a)

In another study using data from the 2020 European Championship, Prudente et al. (2022) evaluated the use of the 7-on-6 attack by comparing the Portugal's strategy, as the team that employed this tactic the most, among the 11 other national teams. The study extracted 123 instances of 7-on-6 attacks, with

Portugal accounting for 68 of these. Overall, most of the 7-on-6 usage occurred when teams were trailing on the scoreboard. The study further revealed that Portugal distinguished itself from other teams by using the 7-on-6 as a permanent game strategy, rather than reserving it solely for the final minutes of play, as other teams tended to do.

A more recent study Manchado et al. (2024) gathered data from 974 empty-goal attacks across 65 matches of the 2022 European Men's Handball Championship, with the aim to characterise the influence of the game context on the use of the empty goal. The game situations were analysed from the video footage of the games. Additionally, the study aimed to quantify the risk of its use and identify the performance variables that influenced the outcome of the empty goal situation. Therefore, the authors established a correlation between the deployment of the 7-on-6 strategy and an eventual negative result in the game. Additionally, the analysis revealed that the probability of a team initiating an attack in a 7-on-6 situation, resulting in a counter-attack and a goal scored with the net empty, is relatively low. However, this probability increases if the attacking team, without the goalkeeper, loses possession of the ball. The authors were unable to identify any performance indicators that could influence the outcome of the 7-on-6.

In addition to the quantitative analysis of actions resulting from the rule allowing attacks without a goalkeeper, it is valuable to consider the opinions of those directly involved in training and competition. Krahenbühl et al. (2019b) conducted a study that gathered the views of four coaches (three Brazilian and one Spanish) form the technical staff who participated in the Brazilian women's handball team, in Olympic cycles between 2013 and 2020. The authors concluded that these coaches believed the new rule enabling a 7-on-6 numerical superiority would be used only during brief moments of the game, and usage of regular empty goal mainly when suffering a 2-minute suspension to avoid offensive numerical disadvantage. with the practice of using the goalkeeper to equalise the game in the event of an exclusion remaining prevalent.

In the studies analysed so far, the opinions of the coaches have been confirmed, as the strategy has been predominantly used to balance the attack during an exclusion situation and only occasionally employed to create a 7-on-6 numerical superiority. Continuing with the approach of considering the perspectives of those directly involved in the application of the rule, Iusepolsky et al. (2022) explored the viewpoints of goalkeepers regarding the new rule. They discovered that most teams did not practise this situation more than twice a week, which could affect the players' confidence in its use.

The use of the goalkeeper as a court player was already occurring before the rule change and only increased with the alteration introduced by the IHF. This was identified in a study that analysed matches during the 2016 European Championship, prior to the publication of the new rule. Musa et al. (2017) examined the use of the goalkeeper playing as an outfield player, observing 48 matches involving 16 teams during the championship. The authors found that teams utilised the goalkeeper as an outfield player on 201 occasions, with the highest usage occurring in the last 10 minutes of each half, particularly by teams trailing on the scoreboard.

The studies carried out so far are largely focused on the statistical success of the use of strategy, without even considering the history and state of the game when coaches use it. Although it is generally accepted that the rules that have been changed over the last few decades have changed the dynamics and rhythm or pace of the game, there are a lack studies that have measured this effect.

In recent years, the IHF has produced a series of technical studies with the objective of evaluating and understanding the evolution of handball in the context of the last few championships (Landuré et al., 2021, 2023). An analysis of the number of attacks, the number of goals and attack time, as illustrated in image 1, indicates that the IHF is concerned with the pace of the game and is examining these variables as a potential means of improving its understanding of the game pace in men, junior and youth competitions.

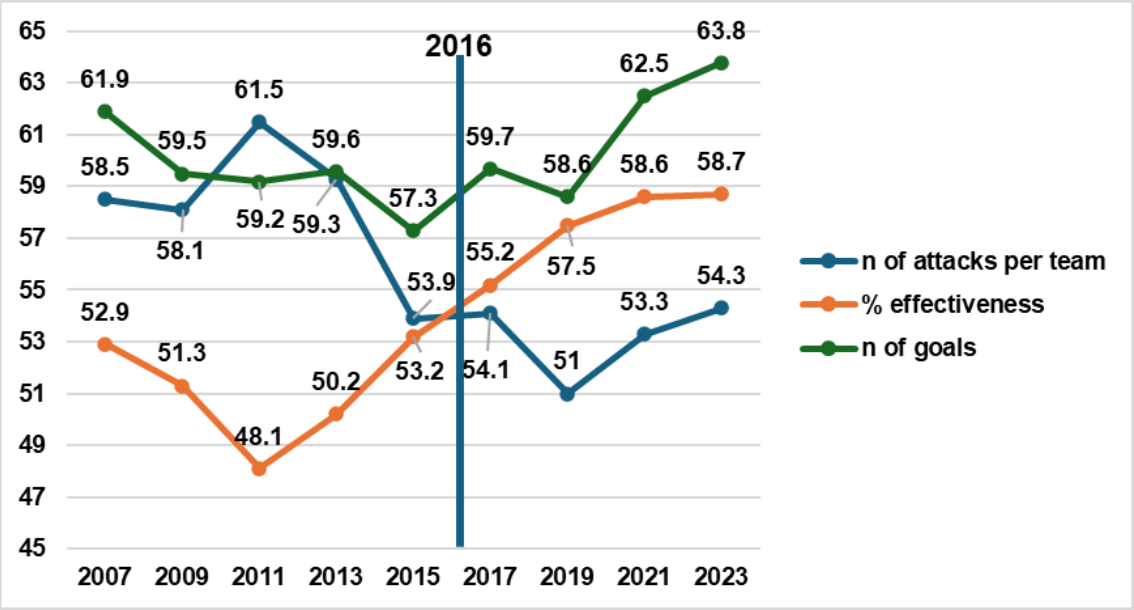

Figure 1 – Trends in the attack performed per team, attack effectiveness and goals, based on the results of the best eight teams at the last Men's World Championships. Plot created using data provided and available by the IHF (Landuré et al., 2021, 2023).

Another topic that the IHF has started to examine in more technical detail is the usage and efficiency of 7-on-6 attacks, based on the data it has collected from the men, junior and youth world championships (Späte, 2021, 2023). Figure 2 illustrates the usage, and the number of goals scored by teams utilising the 7-on-6 during the 2021 World Championship. Furthermore, the IHF supplements this data with information from the 2023 World Youth Championship, which indicates an average of 7.1 attacks and 3.0 goals per game. The Junior World Championship evidenced an average of 6.0 attacks per game and 2.5 goals. Furthermore, the average number of attacks per game during the Men World Championship was 6.3, with an average of 3.0 goals scored.

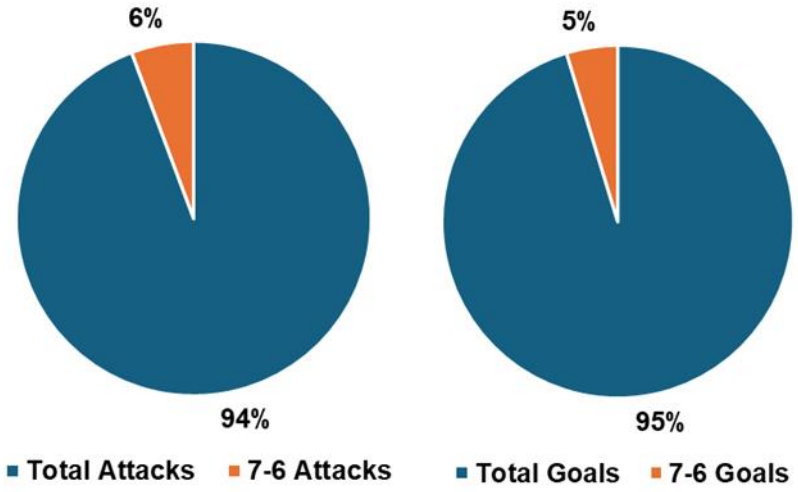

Figure 2 - Usage, and the number of goals scored by teams utilising the 7-on-6 during the 2021 World Championship (Späte, 2021).

The emergence of wearable devices has indeed opened new avenues for analysing game play and pace. However, research on the specific effects of the 7-on-6 game play strategy on players' exertion and game pace levels remains limited. One notable study addressing this was conducted by Gümüş and Gençoğlu (2020b), they investigated small-sided games with female handball players, the effect of 5-on-6 and 7-on-6 with a particular focus on cardiac responses and PlayerLoad. They analyzed PlayerLoad, acceleration, and deceleration data collected through inertial measurement units (IMUs) worn by the athletes. The authors report that there are significant differences in PlayerLoad between the various positions, with goalkeepers exhibiting a lower PlayerLoad than full-backs, centre-backs and wingers. Furthermore, significant differences were observed in cardiac responses, with those of wingers exhibiting lower values than those of centre-backs, forwards and goalkeepers. While this study provides insight into the differences between 5-on-6 and 7-on-6 scenarios, it does not directly compare these with a 6-on-6 game situation. Additionally, the data set does not include information related to defensive play.

Studies highlight the relevance of investigating the game play strategy of attacking with an empty goal (no goalkeeper on the court) in high-demand competition contexts, focusing on collecting quantitative data and understanding physical exertion. Therefore, our study is justified, as it utilizes data collected

during the 2022 Under-20 European Handball Championship. Additionally, this issue seems to be neglected or overlooked, particularly in youth categories.

2.3. Indoor Tracking

Handball is a sport characterised by high-intensity actions and frequent physical contacts with opponents, requiring specific physical abilities from the athletes. In their studies, Buchheit and his colleagues emphasises how handball is a sport of intermittent effort, with interspersed moments of high intensity for the players (Buchheit, 2008; Buchheit & Laursen, 2013a, 2013b). These characteristics make the assessment of the physical demands on players a crucial aspect of training, not only for optimising performance but also for preventing injuries, as noted by Karcher and Buchheit (2014).

However, it is expected that this process will inform how to better adjust training programs and recovery measures, ensuring that athletes' physical capacities are developed safely and effectively. In a review conducted 15 years after the original publication (Impellizzeri, 2003), Impellizzeri et al. (2019) provided an update on the definitions of internal and external training load. External load is defined as the sum of all physical actions performed by an athlete during training or a match, representing the work that induces psychophysiological responses (Bourdon et al., 2017; Gabbett, 2016; Halson, 2014; Impellizzeri et al., 2004; Vanrenterghem et al., 2017) On the other hand, internal load refers to the adaptations occurring in the athlete's body in response to these external demands. This distinction is crucial for understanding the effects of training on the athlete's body, allowing coaches to adjust training loads according to each player's individual response.

The complexity of measuring external load during a handball match is evident due to the sport's dynamic nature, including a high number of players substitutions, the speed of play, and the fact that it is played indoors. This complexity has driven numerous studies focused on effective methodologies for assessing athletes' physical capacities and the effects of different types of training (Manchado et al., 2013). One of the methods widely used in recent years is time-motion analysis (TMA), which involves recording and subsequently analysing players' actions through videos (Manchado et al., 2021). Although this technique (notational analysis) has been recognized as useful, it has been criticized for not

being entirely accurate due to the subjectivity involved in data analysis. As an alternative to TMA, other sports such as football and rugby have utilised the global positioning system (GPS) over the past 20 years to measure athletes' external load during games and training sessions (Kelly et al., 2015). Despite its widespread use in outdoor sports, GPS cannot be used indoors due to signal interference (Fleureau et al., 2020; Font et al., 2021). To address this issue, various companies have developed equipment (WimuTM, CatapultTM, and KinexonTM) that generate a local positioning system (LPS), allowing precise measurement of external load in indoor environments (Bastida-Castillo et al., 2019; García-Sánchez et al., 2023).

The LPS uses ultra-wideband (UWB) technology to accurately track players in indoor settings (2D positional data), where GPS is ineffective due to signal interference (Bastida-Castillo et al., 2019; Fleureau et al., 2020; García-Sánchez et al., 2023). More recently, this technology has been enhanced by the integration of inertial measurement units (IMUs) in wearable devices. This integration enables the measurement not only of athletes' positions but also of critical variables such as acceleration, deceleration, changes in direction, jumps, and impacts, offering a more comprehensive and precise view of players' physical performance (Belmonte et al., 2018; Fleureau et al., 2020; García-Sánchez et al., 2023). The combination of LPS and IMU represents a significant innovation, allowing for a more detailed analysis of external load and helping to tailor training more effectively and personally.

The application of these technologies in handball studies has highlighted the diversity of approaches used to understand the physical demands of the sport. For example, Corvino et al. (2014) investigated the effects of court dimensions on internal and external load in small-sided handball games using GPS equipment to monitor performance variables. This study demonstrated how changes in court size can significantly alter athletes' physical demands, emphasising the importance of adapting training to the specific competitive environment. Complementing this analysis, Luteberget et al. (2017) compared game intensity in situations with different numbers of players, using LPS to measure external load. This type of research is crucial for understanding how

different game configurations can impact players' performance and physiological demands.

Additional research has focused on analysing player performance in specific positions, using combined data from LPS and accelerometery. Oliveira et al. (2014) conducted a detailed study to describe the performance profile of players in different positions during game situations and friendly matches, contributing to the understanding of how players' location and roles influence their physical demands. The authors considered this type a data valuable for developing individualised training programmes that consider the specific needs of each position on the field.

Studies such as those by Barbero et al. (2014) and Ortega-Becerra et al. (2020) explored the activity patterns of elite players in simulated handball matches, as well as the specific demands imposed by different levels of competition. In their work, Moreira (2023) aimed to compare external load metrics based on accelerometery and internal load measured by subjective perception of effort in an elite handball team from the Portuguese 1st Division, over the course of two months. The study revealed a moderate correlation between PSE and external metrics (Accel'Rate, Body Load, Dynamic Stress Load (DSL) and Jerk). In addition, the Body Load and (DSL) metrics, as well as Jerk and Accel'Rate, showed a very strong correlation with each other. The study also analysed the distribution of load in ‘Congested’ and ‘Non-Congested’ weeks, identifying significant variations in load between positions and across weeks.

Also, Freitas (2022) investigated the mechanical load on young elite handball players, comparing playing positions and differences between the first and second half of games, using full-body accelerations. Based on data from 12 EHF Euro M20 2022 matches, variables such as Player Load and jerk were analysed. The results revealed significant differences between positions and between halves of the game, suggesting that the use of multiple metrics is necessary to assess the volume and intensity of the load accurately. The study also highlights the need for future research comparing these external load variables with internal load variables.

These works not only expand knowledge of the physical demands in handball but also underline the importance of advanced technologies like LPS and IMU for collecting accurate and relevant data.

2.4. Game Pace

With the advance of technologies - GPS and multiple camera systems for players and ball tracking - which help to monitor and assess the physical wear and tear of athletes in high-intensity intermittent team sports Waldron and Highton (2014), it became necessary to define a what game pace is exactly and how it can be quantified based on positional and inertial data. As a result, the term “Pace of Play” was coined as a variable to analyse players' physical performance.

In football, several studies have linked pace of play to the distance travelled by a player during a match (Bradley et al., 2010; Bradley & Noakes, 2013; Bradley et al., 2009; Mohr et al., 2003). In addition, studies in football have shown that the management of physical effort and pace of play can be adjusted with prior knowledge of the duration of the game and the state of play, thus allowing players to optimise performance and conserve energy for critical moments in the match (Ferraz et al., 2018; Gabbett, 2015).

Although the distance travelled has been the subject of many studies to determine the pace of play in football, this variable may not be ideal for other team sports. Hughes and Bartlett (2002) argue that because each sport has its own specific characteristics, such as the type of scoring and finishing in matches, the performance indices and consequently the pace of play will be different for each sport. In this perspective, another indoor sport that has been studied for many years with the aim of relating pace of play to performance is basketball.

Studies that have been carried out in the context of basketball have sought to evaluate team statistics, such as shots, rebounds, steals, among others, in order to understand the pace of play and the relationship between winners and losers in games (Csátaljay et al., 2011; Ibáñez et al., 2003; Ibáñez et al., 2008; Sampaio et al., 2010). When we think about handball, this context is a bit different, as it is widely accepted that past matches had a slower pace, with certain moments in the game where an attack could last more than two minutes (Juan Lorenzo Antón, 2010). With all the changes to the rules over the last 20-30 years, the pace of a handball match has intensified greatly, making it one of the fastest indoor team sports and one that is attractive to the public (Landuré et al., 2021).

There is still a lot of debate about the ideal way to monitor the pace of play in handball. (Volossovitch et al., 2010) used the number of possessions to define the pace of the game in their study, the aim of which was to assess whether there was a relationship between the result of a team's previous possession and the opponent's next attack. Karcher and Buchheit (2014), on the other hand, used data on distance travelled to show that even though handball players travel a shorter distance than other sports, their blood lactate and heart rate responses tend to be similar or slightly lower. The high number of changes of direction, moments of alternation between peaks of high intensity and low intensity, the unlimited number of exchanges between the athletes and the amount of physical contact may explain these similarities in the athletes' physiological responses.

More recently, the IHF used data such as the number of attacks, attack time, attack effectiveness, number of goals per game, and the location of shots (end, 6m and 9m lines), to compare and assess whether the pace of handball games is getting faster (Landuré et al., 2021, 2023) . Using data on the location on the court of the shot seems to be a good solution for observing game pace in handball, since the greater the number of quick transitions, the lower the number of 9m shots, as well as making the game more collective, providing a greater number of 2-on-1 and 3-on-2 plays (Landuré et al., 2021).

In this way, we realise that the study of ‘pace of play’ in handball is a critical component in understanding the physical demands placed on athletes during competition. Research has shown that running pace, which is a central aspect of pace of play, varies significantly depending on the phase of play (offensive vs. defensive) and the position of the players on the pitch (Font et al., 2021). Interestingly, research has also observed that female players tend to have a higher average pace than male players, which may be due to differences in playing styles or physical conditioning (García-Sánchez et al., 2023). This knowledge provides essential guidelines for coaches and physical trainers when drawing up specific training plans for each position, which optimise players' performance and, at the same time, try to minimise the risk of overloading and injury.

Calculating the pace of play in team sports has advanced significantly due to the development of kinematic data acquisition and modelling techniques, particularly with the use of high-frequency tracking sensors. These technologies allow for the detailed capture of players' movements on the pitch, resulting in large data sets that can be analysed to identify patterns of pace and game dynamics. According to (Stein et al., 2017), analysing this data involves applying mathematical models that take into account factors such as player speed, distance travelled and interactions between players during the game. These models allow for a more precise understanding of how strategies and tactics influence the pace of the game, thus helping coaches and analysts to optimise team performance.

In addition, data modelling in team sports also uses spatial grid models and network analyses, which segment the field of play and examine how players move and interact in different areas. As pointed out by Antonini et al. (2024), this approach not only helps to quantify the pace of the game, but also provides information on the occupation of space and the transitions between offensive and defensive phases. Integrating this data with machine learning algorithms can also predict patterns of play and player fatigue, offering a comprehensive view of team performance and collective dynamics (Gonçalves et al., 2017).

These techniques represent a significant advance in pace-of-play analysis, allowing for more sophisticated and accurate modelling of dynamics in team sports. The increasing availability of data and the development of new analytical methods will continue to expand the possibilities for study and practical application in this field (Raabe et al., 2023).

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3.Methodology

3.1. Participants

We collected the data during the Men M20 EHF Euro Portugal 2022, occurred between the 7th and 17th of July at Matosinhos, Gaia and Gondomar. As a result of the lack of tracking equipment, it was only possible to gather data at Matosinhos and Gaia. From the 56 games of the competition, were collected data from 27 games, which means 48% of the total games of the competition. Of these 27 matches, both teams were fully tracked in only 17 matches. Based on the purpose of this study, 8 matches were deliberately selected from the fully tracked matches, representing nearly 50% of the total complete match data available. All national teams involved in this subset of games formally agreed to participate.

It's worth noting that all the teams participating in the European Championship were invited to take part. Of these, Croatia, France, Germany, Iceland, Italy, Montenegro, Portugal, Serbia, Slovenia, Spain, and Sweden formally accepted the invitation.

Although most of the teams had previously agreed to participate, in three cases it was decided just before the data collection that the players would not use the tag. In one case, this was because it was uncomfortable to wear an additional tag when they already had their own system, and in two other cases, the athletes stated moments before the game (at locker room) that they didn't feel comfortable using the equipment - It's worth noting that the matches in question were very important for their classification.

Additionally, since only two complete tracking systems were available, it wasn't possible to install the equipment in all the venues allocated for the competition.

3.2. Data acquisition

The tracking device equipment used was the WIMU PRO (RealTrack Systems, Almería, Spain), a 20 Hz local positioning system with an ultra-wide band radiofrequency technology. To have enough devices for two complete handball teams (32 players maximum), two sets of WIMU PRO were used,

comprised of 23 and 15 devices (70 g, 81 x 45 x 16 mm) each, but only one set of 8 antennas was used to synchronise both systems.

The antennas were placed around the court in an octagon shape design. Then, due to safety matters, the antennas were tied to the venue stand's protection balcony with zip cable ties at a height of, approximately 2.50 metres. The distance between antennas and to the court is described in the figure 1 (all the distance values were measured with a Bosch laser telemeter device).

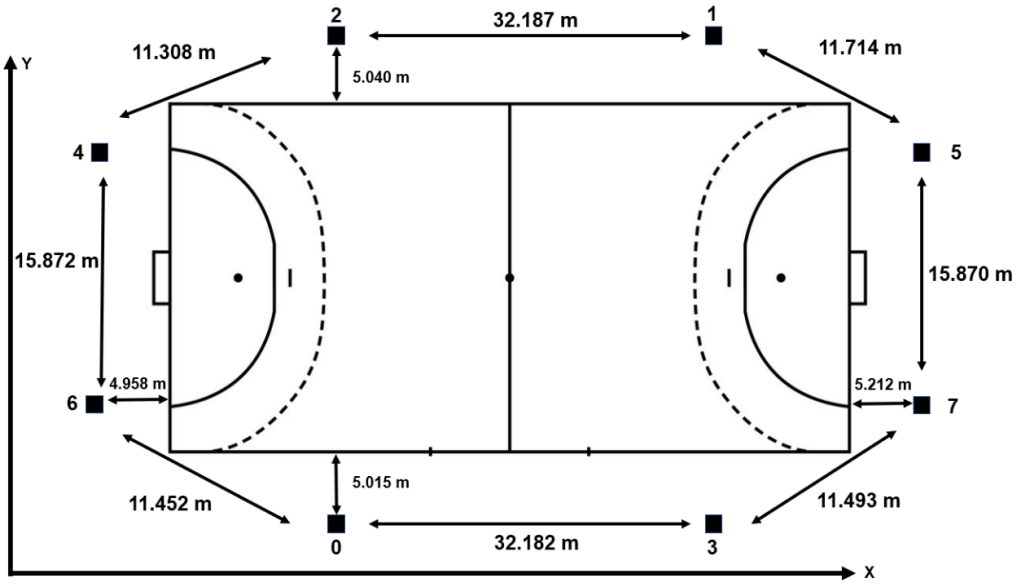

Figure 3 - Matosinhos Court and Antennas Placement with respective distances.

The devices were set to register at a frequency of 20 Hz for the positional data and 100 Hz for the inertial sensors. It is worth mentioning that, although it is possible to set the inertial sensors' data frequency measuring at 1000 Hz, the 100 Hz frequency band was chosen to reduce the data files size, henceforth easing the data processing, treatment, and analysis, in addition to a guarantee of longer battery duration, as it was recommended by the system's company technician.

The players used a chest-worn vest tight to the body with a pocket to insert the tracking device, placed on the upper back around the T4-T5 vertebrae. It is worth mentioning that it was required to use similar vests from other brands as some vests were not large enough to fit some of the bigger players.

3.3. Procedures

This study was embedded in a major project between the Faculty of Sports of Porto (FADEUP) and University of Trás-os-Montes and Alto Douro (UTAD). Due to the scale of the project, a collaboration protocol between University of Porto (UP), FADEUP, UTAD and the EHF was obligatory so all national federations involved in the competition would consent and authorize to be in the project in order to be possible to collect the data necessary. The Portuguese Handball Federation was also involved in the study by supplying financial aid to cover the logistic costs. Participation from the national teams in competition was voluntary and, at any moment of the data collection, any team or player had the opportunity to refuse to participate. It was necessary to require formal authorization from the Centro de Investigação Formação Inovação e Intervenção em Desporto (CIFIID) and from the Polytechnic Institute of Castelo Branco (IPCB) to utilize all the necessary equipment. Additionally, given the project data was also utilized for a UTAD PhD student's thesis, the project was submitted to and approved by the Ethics Committee from UTAD.

On the first gameday eve, the tracking system was installed, synchronised, and calibrated with the help of a technician from the system manufacturer. The synchronisation and calibration process were repeated on each game day to check if there were any anomalies and if the devices were fully operational.

Usually, the players arrived at the venue 90 minutes ahead of the game and were given a set of vests of varied sizes and types and were left to find what size and type suited them best. The players warmed up with the vest but not with the device as this would lead expected in-game device outages in the latter games of the day. Therefore, the devices were put on by the research team members between the end of the warm-up and the teams' presentations. After the game, the devices were taken out from the players' backs with the help of the staff members and put in the smart stations to recharge for the following game.

3.4. Kinematic variables

3.4.1 Jerk

Researchers have proposed the use of composite measures based on the rate of change of acceleration, referred to as 'jerk' in classical physics, as a means of quantifying the change in force exerted on the body (Eager et al., 2016). The jerk is calculated as the sum of the jerk norm (equation 1), also known as the change in acceleration over time Eager et al. (2016) and its unit of measurement in the reduced form is G.

$$\text{match-jerk} = \sum_i \left\| \frac{d\vec{a}}{dt} \right\|_i \cdot \Delta t_i \tag{1}$$

3.4.2 Dynamic Stress Load (DSL)

The (DSL) (equation 2) was firstly published by (Gaudino et al., 2015). The metric is defined as the sum of the weighted acceleration-based impacts over 2G, where an impact of 4G is more than twice as damaging as an impact of 2G Gaudino et al. (2015), since the exponent is defined as three, its unit of measurement in its reduced form is G3·s (“G cubed seconds”). The acceleration norm vector for the match-DSL was smoothed through a moving average with a 0.1-second window. This metric that has already been used in Soccer (Pino-Ortega et al., 2021), Rugby (Stevens et al., 2024), and Handball (Freitas & Estriga, 2024).

$$\text{match-DSL} = \sum_i (t_{i+1} - t_i) \cdot \text{IMPACT}_i^3, \quad \text{IMPACT}_i = \begin{cases} \|\vec{a}_i\|, & \|\vec{a}_i\| > 2G \\ 0, & \text{else} \end{cases} \tag{2}$$

3.4.3 Locomotive Metrics

For this metrics we considered the total distance covered, and the HSR. The values used to define HSR in handball have been arbitrary, lacking both validation and consensus among researchers, they have varied considerably, from 4 to 5.5 m/s^{-1} (Fleureau et al., 2020; Manchado et al., 2021; Manchado et al., 2020). We decided to follow the Freitas and Estriga (2024) study, whose values was defined as 4.4 $m.s^{-1}$.

3.5. Game tactical variables and performance indicators

The handball game is usually considered to have two major game phases (attack and defence), depending on whether the team has the ball or not. Each phase can be further divided into positional (positional attack and positional defence) and transitional (defence-attack transition and attack-defence transition) categories (Estriga, 2019).

Despite Olympic handball being played with seven players on each side, variations in game play can occur due to player 2-minute suspension and strategic-tactical team decisions, which may result in different attacker-defender ratios during transitional and positional play. For the current study the following tactical structures variables was considered to investigate the game state as described in the table 1

Table 1 - Game positional play state variables

Game play status	Description
(Gk+) 6-on-6 (+Gk)	A game play situation when both teams have six players on the court and the goalkeeper remains in the goal area
7-on-6 (+Gk)	A game play situation when the attacking team has a numerical advantage by replacing the goalkeeper with a seventh player.
Post 7-on-6 (+GK)	A game situation in which the team takes possession of the ball after defending at a numerical disadvantage (with the opposing team attacking 7-on-6). Leading to different temporary game play scenarios (or states): - (GK+) 6-on-7, without a goalkeeper protecting the goal, as they haven't yet been able to substitute a court player for the goalkeeper (who is either still on the bench or running toward the goal). (GK+) 6-on-6 (+GK), meaning the team that lost possession after playing 7-on-6 (+GK) managed to stop the opposing team's fast attack, substitute players, and reorganize their defensive system.

* Concepts defined based on the IHF (Landuré et al., 2021, 2023; Späte, 2021, 2023).

Other game play variables were defined as follows:

- Average number of players involved in each possession: players that participate actively in ball handling during an offensive sequence.
- Average number of passes completed in each possession.
- Average duration (in seconds) of each possession: this variable measures how long a team holds onto the ball before a shot attempt or loss of possession.

Table 2 presents the performance indicators utilized in the current study.

Table 2 - Performance indicators

Performance indicators*	Description
Attack Effectiveness	Ratio between the number of ball possessions and the number of goals scored
Goal Effectiveness	Ratio between the number of shots and the number of goals
Goalkeeper Effectiveness	Ratio between the number of shots and the number of saves made by the goalkeeper

* Concepts defined based on the IHF (Landuré et al., 2021, 2023; Späte, 2021, 2023).

3.6. Data Processing and synchronization

At the end of each game, a (.csv) file was generated and extracted for each player. These files contained 2D coordinate data for the players (x, y), which was obtained using software (SPRO) provided by the tracking device manufacturer. Although the exported files were in a raw data format, it is important to mention that the software applies an internal signal filtering process, which we have no control over, before making the data available for export. Therefore, no additional data filtering was used. However, a preprocessing step was conducted to address missing spatio-temporal data using interpolation methods such as cubic splines.

Additionally, we had access to the full video recordings of the matches, providing an uninterrupted view of the full players actions. Based on this footage, all selected matches for this study were analysed, utilising slow-motion replays as needed, and events were coded with specific markers according to predefined

rules for each event (Table 1), using open-source subtitle editing software. Subsequently, a list of events with corresponding timestamps was created and saved in an Excel file. This process enabled the synchronisation of data using manually logged start and end markers to combine the information before kinematic data processing.

Table 3 - Codes description for data synchronization

Code	Game Action	Description
BO	Ball out	Moment the ball leaves the line behind the goal
BOS	Ball out sideline	Moment the ball leaves the sideline
BOP	Ball on post	Moment the ball touches the goal
GL	Goal	Moment the ball enters the goal
PB	Pass ball	Moment the ball leaves the passer's hand
CB	Catch ball	Moment the player receives the ball
TB	Touch ball	Moment when a player touches the ball but doesn't take control of it
DT	Defense touch	Moment when a defender touches the ball without taking control of it
S	Shot	Moment when the player takes a shot
PS	Penalty shot	Moment when the player takes a shot from 7m
AF	Atack foul	When an attacking player commits an attacking foul
SB	Steal ball	When a defender regains possession of the ball
SGK	Successful goalkeeper	When the goalkeeper makes a save
DF	Defense foul	When a defender commits a foul
PF	Penalty foul	When a defence player commits a 7m foul
RC	Red card	When a player receives a red card
Code	**Ball Possession**	
AB+CNT	Atack Ball + Country	We define attacking possession as all the time a team has kept the ball under its control (Silva et al., 2013)
Code	**Ball Possession**	
STFP	Start transitional fast play	Start of the fast transition (from defence to attack), when a team, after recovering the ball or conceding a goal, moved from their defence to the attacking field without substituting their players and tried to create a shooting situation without the defence being fully organised (Estriga, 2019).

STSP	Start transitional slow play	Slow defence-attack transition start (Estriga, 2019), hen a team, after regaining possession or conceding a goal, made a transition in which offensive exchanges took place and allowed the defence to make substitutions and organise the positioning of their players.
SPP	Start position play	The beginning of the team positional attack refers to the moment after a fast or slow transition when the attacking system is established to initiate the set play, following substitutions and players' positioning (Silva et al., 2013).
Code	**Ball Possession**	
SG	Start game	The moment the game begins
FG	Finish game	The moment the game ends
F1H	Finish first half	Moment the first half ends
S2H	Start second half	Moment when the second half ends
ST	Start time out	Moment when the game is stopped by the referees
FT	Finish time out	Moment when the game starts again after the referees have called a halt.
SCT	Start coach time out	Moment when play is stopped at the request of a coach
FCT	Finish coach time out	Moment when play resumes at the request of a coach.
S2MS	Start 2 min suspension	Moment when a player receives a 2-minute suspension
F2MS	Finish 2 min suspension	Moment when the 2-minute suspension ends
SEG	Start empty goal	Moment when the goalkeeper is substituted
FEG	Finish empty goal	Moment when the goalkeeper returns to the goal
SPA	Start passive atack	Moment when the referee signals the start of the passive attack
FPA	Finish passive atack	Moment when the passive attack is finalised, either by a shot or an attacking foul
SIV	Start video interference	Moment when the video is interfered with, and the game cannot be seen
FIV	Finish video interference	Moment when the video interference ends, and the game cannot be seen

Furthermore, a marker was used to indicate when a player held or released the ball. This allowed us to determine the ball's position on the court (x, y) and whether it was in a player's possession (grabbed) or in motion through the air (flying)

3.7. Statistical Analysis

Exploratory descriptive statistics were conducted for all the events and variables considered, including the mean, standard deviation, frequency of occurrence, median, minimum, and maximum values. Offensive game ratios, such as shots/goals and both absolute and relative efficiencies, were calculated. A Shapiro-Wilk test was done to every group data to detect normality, with a significance level of < 0.05 Given that the data in each set of game play variables showed a non-normal distribution, the Kruskal-Wallis H-test was applied to compare the observations, using a p-value threshold of < 0.05 for significance. If significant differences were found, post-hoc analysis was conducted using Dunn's Test with Bonferroni correction for pairwise group comparisons. For the DSL and HSR distance metric only the top 25% (fourth quartile) player-match observations were considered. Extreme outliers were excluded from the dataset using the interquartile range (IQR) method. Data points that deviated from the interquartile range by more than 3 times were identified as outliers and removed. To quantify the effect size, Cohen's *dz* test was performed, the effect sizes were described with the following classification: trivial < 0.1, small $= 0.1$ - 0.29, medium $= 0.3$ - 0.49, large > 0.5 (Field, 2017).

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4. Results

4.1. Game data description and performance indicators

Given this study objectives, in the 8 matches analysed, we observed a total of 982 attacking game play situations or attack sequences, time a team has kept the ball under its control. Table 4 presents an overview of the match variables and performance indicators, with an average per team.

Table 4 - Descriptive data

	per team
Attacks (n)	61.4
Attack Duration (s) (mean ± SD)	29.5 ± 19.10
Shots (n)	53.3
Goals (n)	29.8
Goalkeeper Saves (n)	12.6
Attack Effectiveness	48%
Goal Effectiveness	56%
Goalkeeper Effectiveness	24%

Table 5 provides an overview of the obtained game play statistics, divided per on-court attackers defenders ratio considered for this work: (GK+) 6-on-6 (+Gk), 7-on-6 (+Gk) and post 7-on-6 (+Gk) game play situations. It should be noted that 162 of the attack situations were excluded from the analysis because a 2-minute suspension of a player occurred during those sequences, affecting the players ratio between the teams. This meant that during the same ball possession, two different game play states were present. Excluding these attacking situations was necessary, as these occurrences (game play stops due to a player's suspension) is expected to alter the game play dynamics between the teams and influence their strategic approaches. Typically, a team down a player removes the goalkeeper to add an attacker to compete on equal numbers. In summary, to avoid analysing full ball possession sequences with differing

player numbers that might impact tactical and strategic decisions, these situations were excluded from the current study.

Table 5 - Total Matches Statistics according to attackers-defenders ratio

	(GK+) 6-on-6 (+Gk)	7-on-6 (+Gk)	Post 7-on-6(*)
Attacks (n)	698	61	61
Shots (n)	595	50	58
Goals (n)	325	27	40
Goalkeeper Saves (n)	138	16	11
Attack Effectiveness	47%	44%	66%
Goal Effectiveness	55%	54%	69%
Goalkeeper Effectiveness	23%	32%	19%

(*) A game situation in which the team takes possession of the ball after defending at a numerical disadvantage (with the opposing team attacking 7-on-6).

Table 6 presents the descriptive statistical data concerning positional attacks in the 6-on-6 and 7-on-6 scenarios.

Table 6 – Statistics from positional attack in equal numbers or numerical advantage

	(GK+) 6-on-6 (+Gk)	7-on-6 (+Gk)
Attacks (n)	364	41
Attack Duration (s) (mean ± SD)	22.51 ± 13.4	24.1 ± 18.9
Shots (n)	330	41
Goals (n)	169	18
Goalkeeper Saves (n)	82	14
Attack Effectiveness	46%	44%
Goal Effectiveness	51%	44%
Goalkeeper Effectiveness	25%	34%
Passes Complete (n) (mean ± SD) (*)	17.2 ± 5.3	15.9 ± 7.0
Players Involved (n) (mean ± SD) (*)	5.4 ± 0.9	5.9 ± 1.2

(*) As a result of the need for further corrections and improvements to the Python code to detect and resolve synchronization issues, this variable still includes the time and events that occurred during the transition.

For each game play situation under analysis, the relative time spent (percentage) by the teams in each of the sub-attacking phases—slow transition, fast transition, and positional attack—is illustrated in Figure 4.

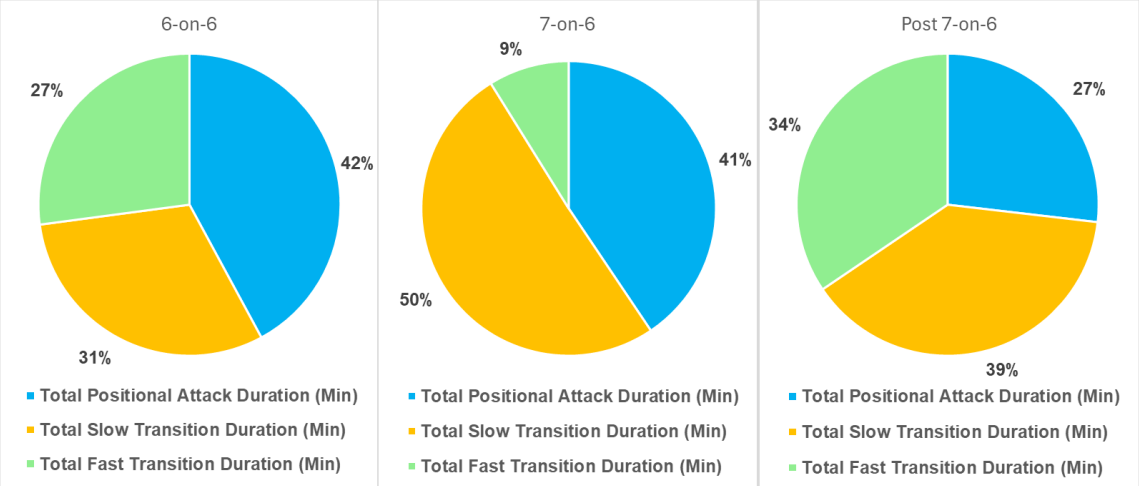

Figure 4 - Percentage of time the teams spent in each of the sub-attacking phases: slow transition, fast transition, and positional attack.

The total number of attacks observed in the current study was 982. Of these, 6% were with a numerical advantage (7-on-6). However, the number of matches studied per team-country was not equal. It is interesting to note that the teams used the 7-on-6 strategy differently, with the time they played in this format varying from zero to an average of 14 times per match (as displayed in Figure 5).

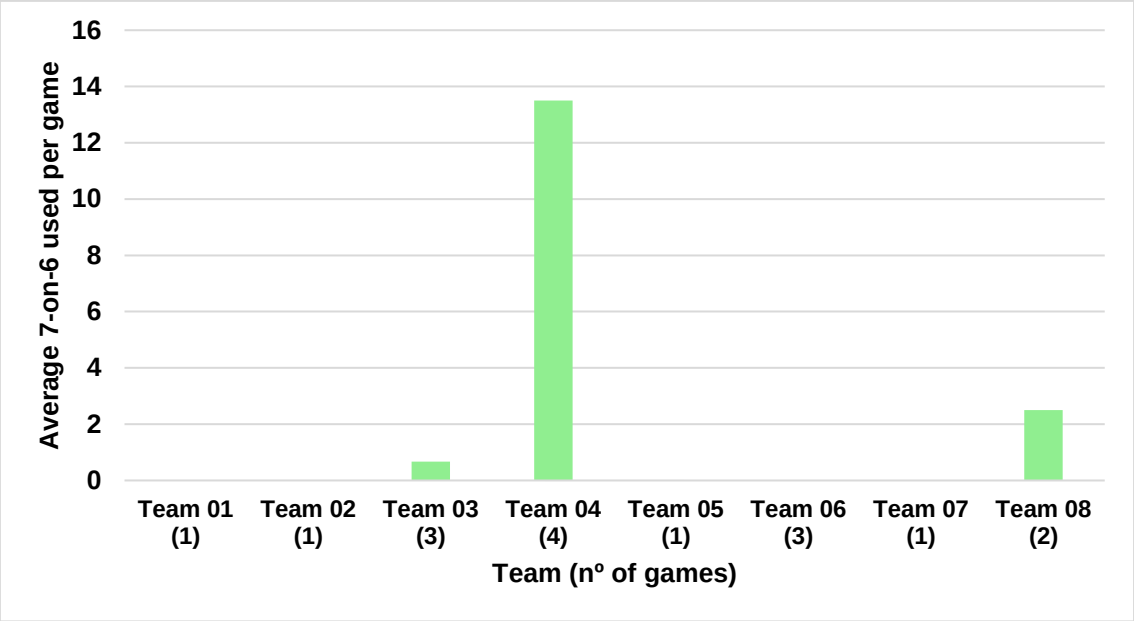

Figure 5 - Average number of times each observed team employed the 7-on-6 (+GK) strategy.

A further topic of interest is the difference in goals when a team decides to use 7-on-6, for which the relevant data is presented in Figure 6. The descriptive results are presented in the table 6.

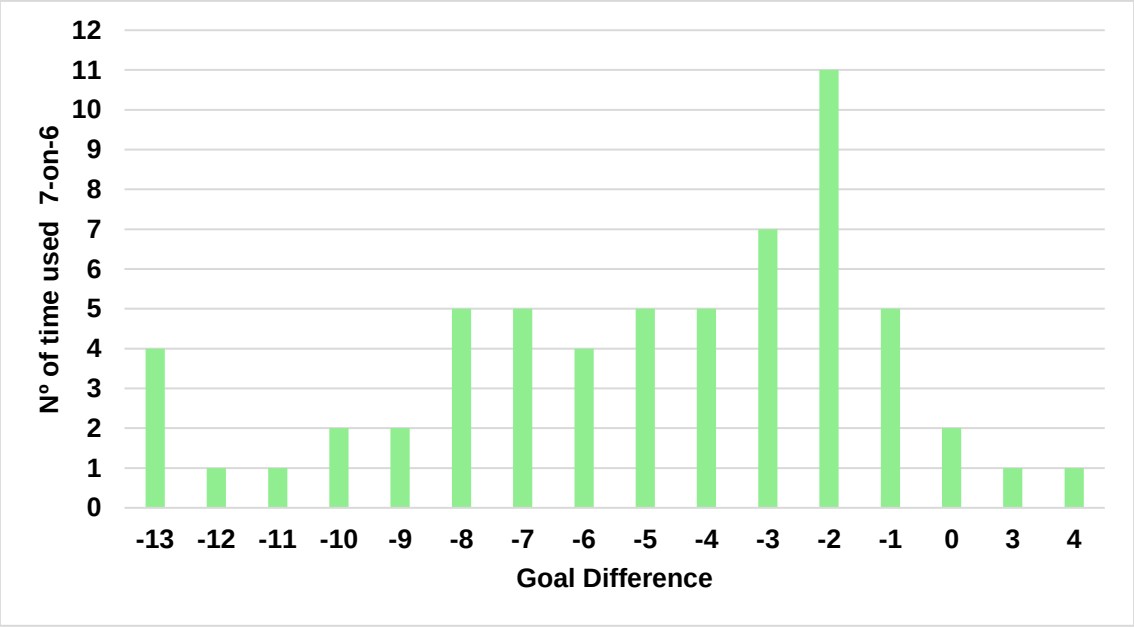

Figure 6 - Scoring difference at the time a team employed the 7-on-6.

Table 7 - Descriptive data regarding the scoring difference at the time a team employed the 7-on-6.

		(GK+) 6-on-6 (+Gk)	7-on-6 (+Gk)	Post 7-on-6(*)
Goal Difference	Mean ± SD	-0.2 ± 7.3	-4.9 ± 3.8	4.4 ± 3.8
	Max	16.0	4.0	13.0
	Median	0.0	-4.0	4.0
	Min	-16.0	-13.0	-4.0

(*) A game situation in which the team takes possession of the ball after defending at a numerical disadvantage (with the opposing team attacking 7-on-6).

Regarding the difference in goals at the start of possession, significant differences were found between the three game play configurations (H (2) = 57.28, p-value < .001), where 6-on-6 showed significantly higher values than 7-on-6 (p-value < .001, *dz* = 0.19) and significantly lower than post 7-on-6 (p-value < .001, *dz* = -0.19). Also, the 7-on-6 were significantly lower than the post 7-on-6 (p-value < .001, *dz* = 0.74).

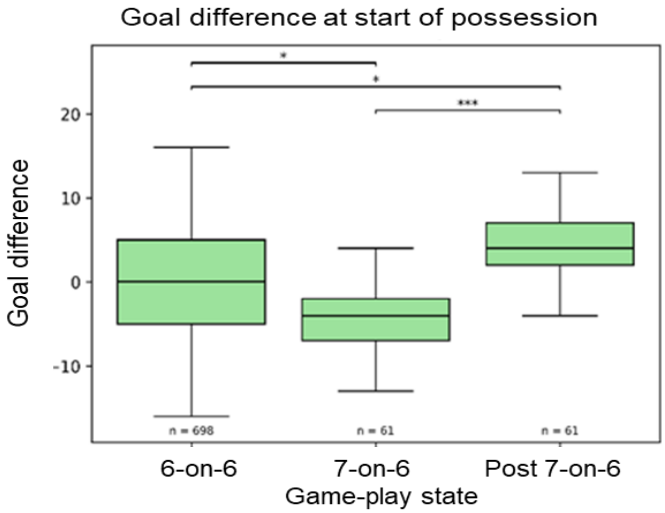

Figure 7 - Boxplots of goal difference at start of possession in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

4.2. Game Pace and attackers-defenders ratio

Several events or variables were considered of interest to analyse what occurred during and after game play, whether teams were playing with equal or

different numbers of players and with or without a goalkeeper protecting each team's goal.

The descriptive results of some game pace and game play variables are presented in Table 7.

Table 8- The game pace descriptive matches statistics regarding attacks duration (seconds), completed number of passes, as players involved, and defensive fouls made by opposition according to attackers-defenders ratio

		(GK+) 6-on-6 (+Gk)	7-on-6 (+Gk)	Post 7-on-6(*)
Attack Duration (seconds)	Mean ± SD	27.89 ± 18.80	39.94 ± 19.05	21.22 ± 14.87
	Max	100.38	110.67	47.92
	Median	29.53	33.50	18.90
	Min	1.30	10.30	2.35
Complete Passes (n)	Mean ± SD	10.9 ± 8.09	14.5 ± 6.4	7.8 ± 6.6
	Max	36.0	35.0	25
	Median	12.0	13.0	6
	Min	0.0	5.0	0.0
Players Involved (n)	Mean ± SD	4.4 ± 1.6	5.8 ± 1.1	3.9 ± 1.9
	Max	8.0	9.0	7.0
	Median	5.0	6.0	4.0
	Min	1.0	4.0	1.0
Defensive fouls made by opposition (n)	Mean ± SD	0.3 ± 0.7	0.6 ± 0.8	0.2 ± 0.4
	Max	5.0	2.0	1.0
	Median	0.0	0.0	0.0
	Min	0.0	0.0	0.0

(*) A game situation in which the team takes possession of the ball after defending at a numerical disadvantage (with the opposing team attacking 7-on-6).

Regarding duration of possession, significant differences were found across the three game play configurations (H (2) = 20.31, p-value < .001), where the 7-on-6 showed significantly higher values than the 6-on-6 (p-value < .001, d_z = 0.15) and post 7-on-6 (p-value < .001, d_z = 0.41). No differences were observed between the 6-on-6 and post 7-on-6 (p-value = 0.278, d_z = 0.06).

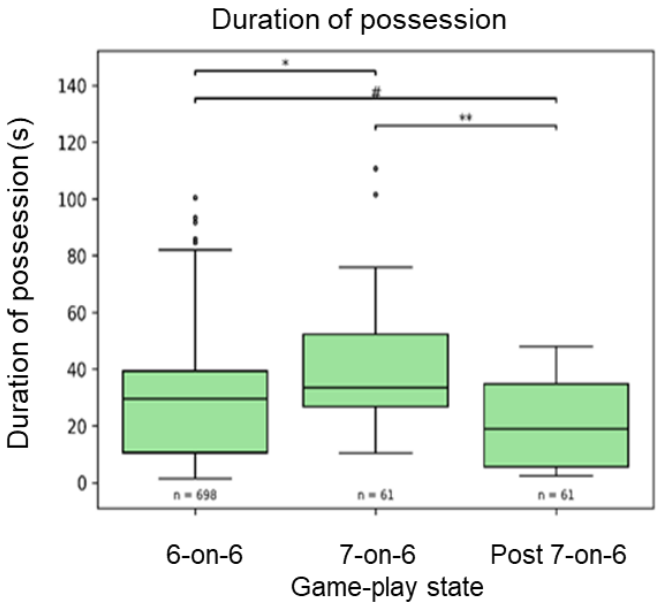

Figure 8 - Boxplots of duration of possession in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

Regarding number of passes completed, significant differences were found across the three game play configurations (H (2) = 15.14, p-value < .001), where the 7-on-6 showed significantly higher values than the 6-on-6 (p-value < .001, d_z = 0.11) and the post 7-on-6 (p-value < .001, d_z = 0.37). No differences were observed between the 6-on-6 and post 7-on-6 (p-value = 0.105, d_z = 0.08).

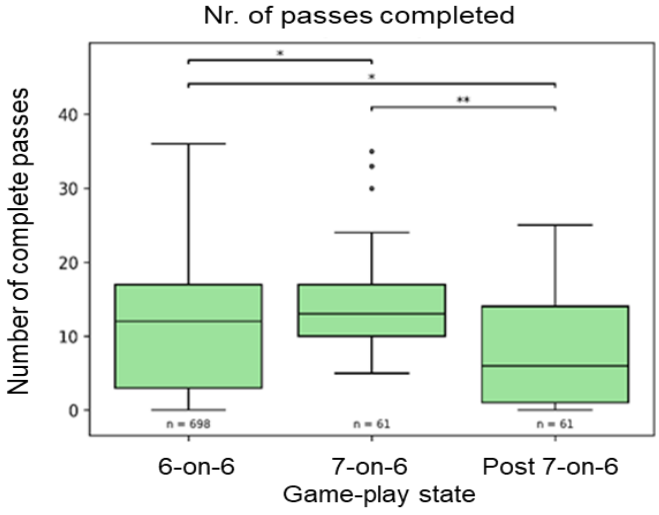

Figure 9 - Boxplots of number of passes completed in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

Regarding number of players involved, significant differences were found across the three game play configurations (H (2) = 36.96, p-value < .001), where

the 7-on-6 showed significantly higher values than the 6-on-6 (p-value < .001, d_z = 0.22) and the post 7-on-6 (p-value < .001, d_z = 0.48). No differences were observed between the 6-on-6 and post 7-on-6 (p-value = 1.00, d_z = 0.03).

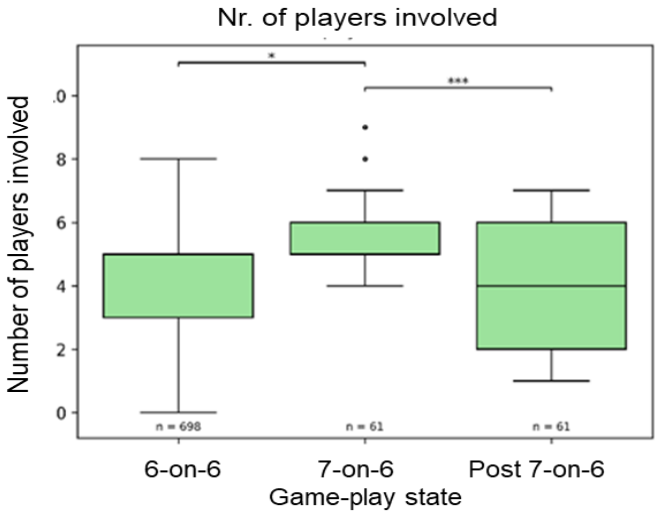

Figure 10 - Boxplots of number of players involved in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

Regarding defensive fouls made by opposition, significant differences were found across the three game play configurations (H (2) = 29.75, p-value < .001), where the 7-on-6 showed significantly higher values than the post 7-on-6 (p-value < .001, d_z = 0.42). No differences were observed between the 6-on-6 and 7-on-6 (p-value = .013, d_z = 0.11), and between 6-on-6 and post 7-on-6 (p-value = .013, d_z = 0.11).

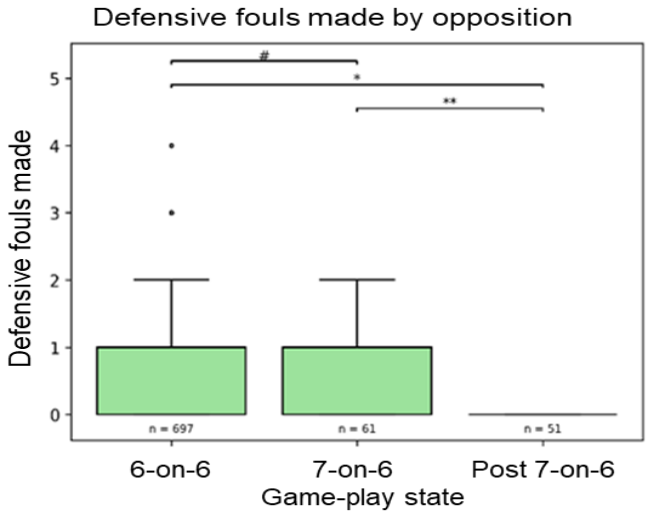

Figure 11 - Boxplots of number of defensive fouls made by opposition per ball possession in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

Regarding duration of the attack phase, no differences were found across the three game play configurations (H (2) = 9.48, p-value = .009). But it should be noted that the transitional phase was not excluded from the data.

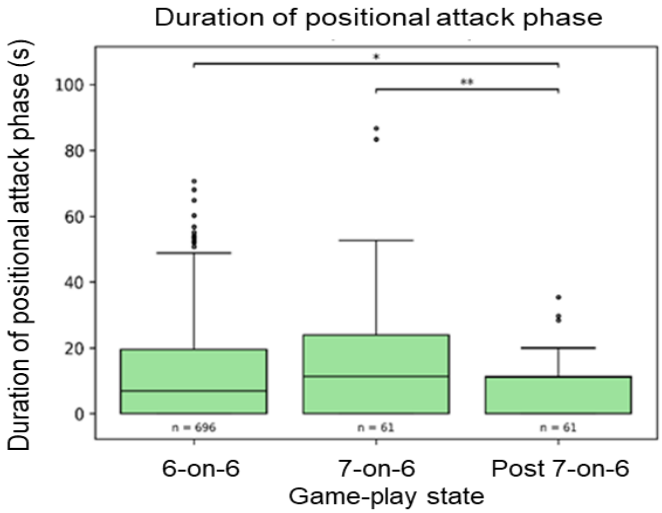

Figure 12 - Boxplots of duration of positional attack phase in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

When analysing only the transition phase previously classified as slow, significant differences were found across the three game play configurations (H (2) = 40.39, p-value < .001), where the 7-on-6 showed significantly higher values

than the 6-on-6 (p-value < .001, d_z = 0.22) and post 7-on-6 (p-value < .001, d_z = 0.41). No differences were observed between the 6-on-6 and post 7-on-6 (p-value = 1.00, d_z = 0.00).

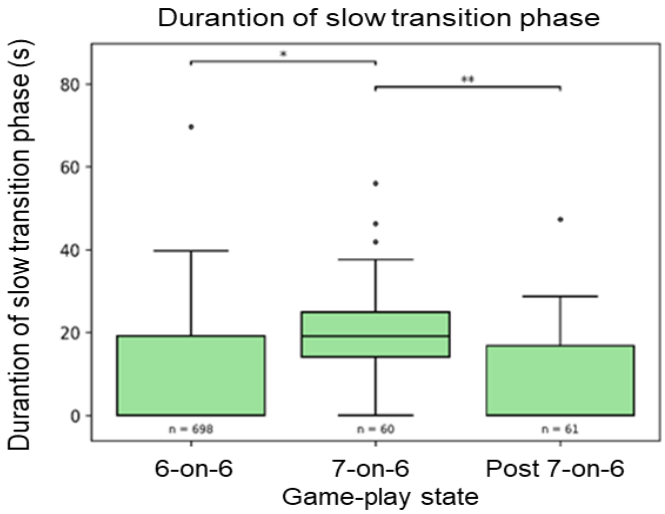

Figure 13 - Boxplots of duration of slow transition phase in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

Regarding duration of the transition phase, previously classified as fast, significant differences were found across the three game play configurations (H (2) = 47.73, p-value < .001), where the 7-on-6 showed significantly lower values than the 6-on-6 (p-value < .001, d_z = -0.26) and post 7-on-6 (p-value < .001, d_z = -0.50). No differences were observed between the 6-on-6 and post 7-on-6 (p-value = 1.00, d_z = 0.01).

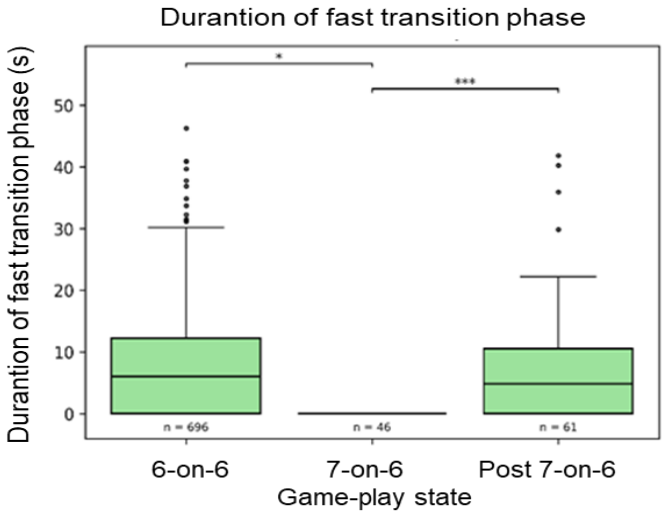

Figure 14 - Boxplots of duration of fast transition phase in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

4.3. Game Physical Exertion and attackers-defenders ratio

Regarding the computed DSL metric values in the attack phase, no differences were observed significant differences were found across the three game formats (H (2) = 2.87, p-value = .238).

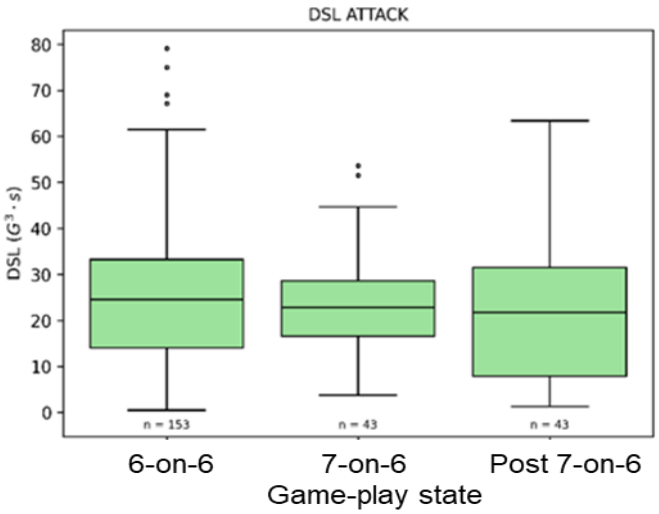

Figure 15 - Boxplots of DSL values obtained in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

Regarding the DSL values obtained for the defence phase, no significant differences were observed when opposing the three game play configurations used by the attacking team (H (2) = 2.72, p-value = .256).

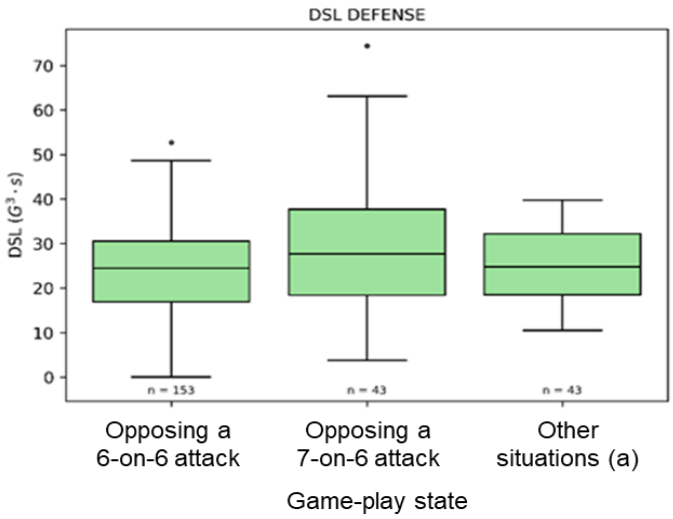

Figure 16 - Boxplots DSL defense in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***). (a) Other Defence situations.

Regarding jerk values observed in the attack phase, significant differences were found across the three game play configurations (H (2) = 38.25, p-value < .001), where the 7-on-6 showed significantly higher values than the 6-on-6 (p-value < .001, *dz* = 0.43) and post 7-on-6 (p-value < .001, *dz* = 0.48). No differences were observed between the 6-on-6 and post 7-on-6 (p-value = 1.00, *dz* = 0.03).

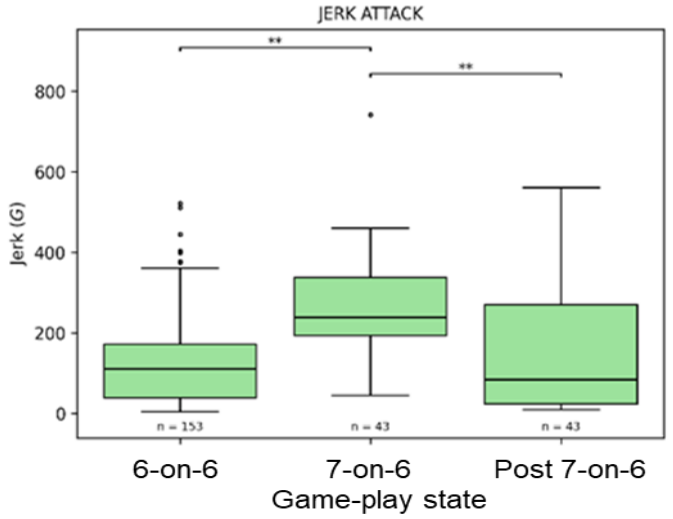

Figure 17 - Boxplots jerk attack in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

Regarding jerk values in the defence phase, when opposing the three game play configurations used by the attacking team significant differences were

found (H (2) = 23.65, p-value < .001), where the 7-on-6 showed significantly higher values than the opposing 6-on-6 (p-value < .001, *dz* = 0.34). No differences were observed between the defence values against opposing 6-on-6 and post 7-on-6 (p-value = 0.331, *dz* = 0.11) and between the opposing 7-on-6 and post 7-on-6 (p-value = 0.02, *dz* = 0.27).

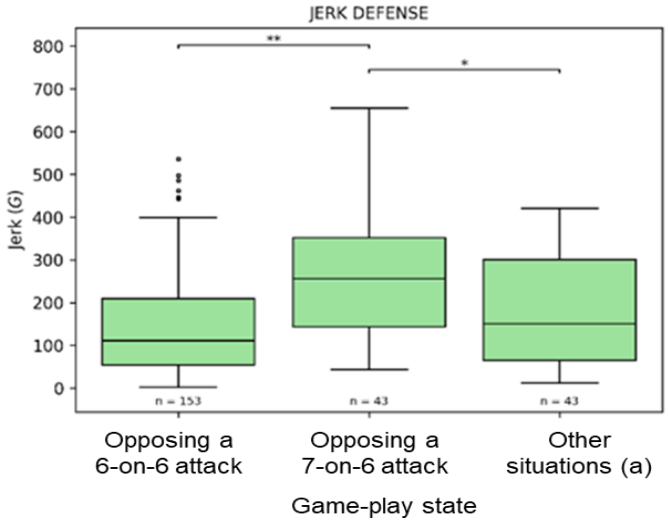

Figure 18 - Boxplots jerk defense in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***). (a) Other Defence situations.

Regarding distance covered when attacking, significant differences were found across the three game play configurations (H (2) = 37.35, p-value < .001), where the 7-on-6 showed significantly higher values than the 6-on-6 (p-value < .001, *dz* = 0.42) and post 7-on-6 (p-value < .001, *dz* = 0.52). No differences were observed between the 6-on-6 and post 7-on-6 (p-value = 1.00, *dz* = 0.00).

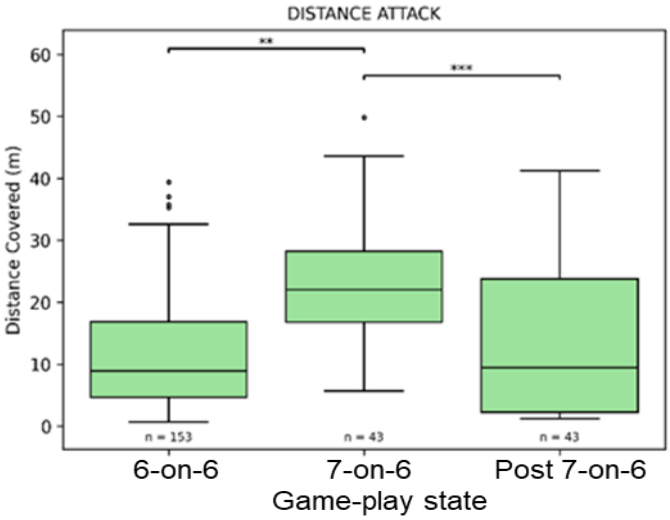

Figure 19 - Boxplots distance attack in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

Regarding distance covered by the defenders , when opposing the three game play configurations used by the attacking team significant differences were found (H (2) = 34.44, p-value < .001), where defending against 7-on-6 showed significantly higher values than when facing 6-on-6 (p-value < .001, *dz* = 0.41) and post 7-on-6 (p-value < .001, *dz* = 0.43). No differences were observed when defending against 6-on-6 and post 7-on-6 (p-value = 1.00, *dz* = 0.05).

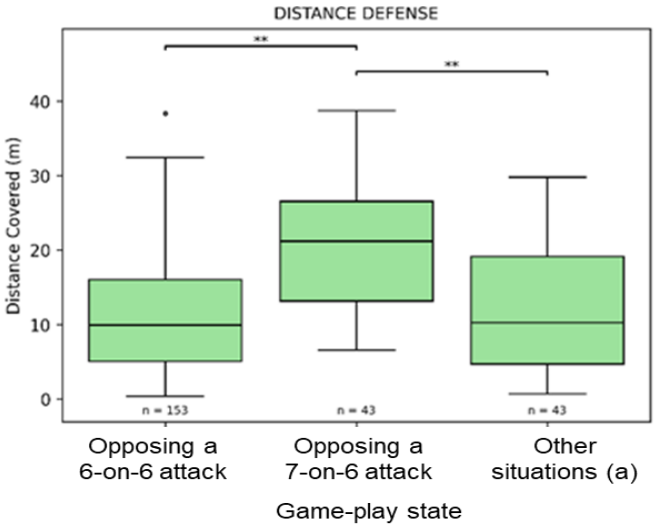

Figure 20 - Boxplots distance defense in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***). (a) Other Defence situations.

Regarding HSR distance attack, significant differences were found across the three game play configurations (H (2) = 25.08, p-value < .001), where the 7-

on-6 showed significantly lower values than the 6-on-6 (p-value < .001, *dz* = -0.31). No differences were observed between the 6-on-6 and post 7-on-6 (p-value = 0.02, *dz* = 0.18) and between the 7-on-6 and post 7-on-6 (p-value = 0.45, *dz* = 0.16).

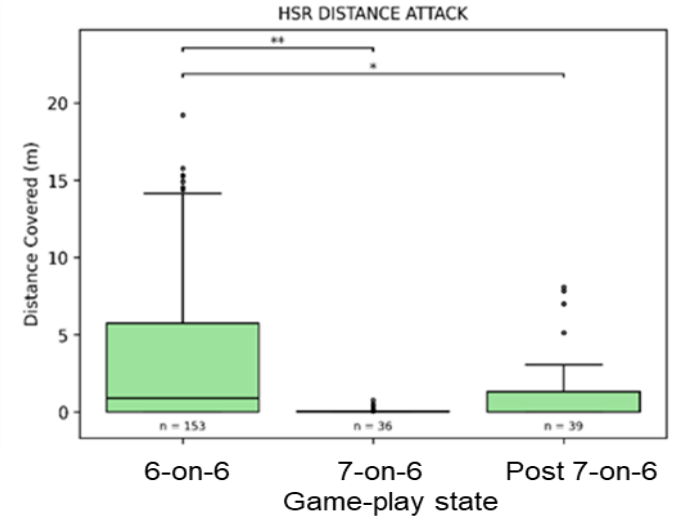

Figure 21 - Boxplots HSR distance attack in each game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***).

Regarding HSR distance defence, no differences were observed significant differences were found when opposing the three game play configurations (H (2) = 0.38, p-value = .827).

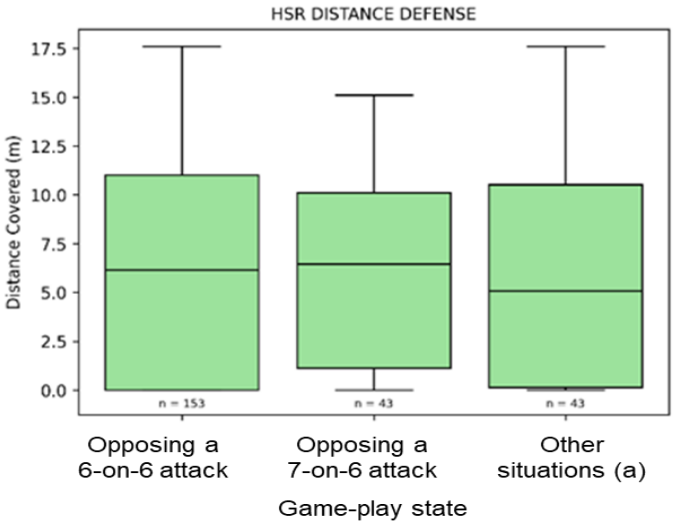

Figure 22 - Boxplots of HSR distance in defense according to the attacking team's game format. Significant differences marked as: trivial (#), small (*), medium (**) and large (***). (a) Other Defence situations.

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5. Discussion

5.1. Exploring the Attackers-Defenders Ratio and Game play Effectiveness

When the subject of this study was first thought, one of the initial research questions that emerged was whether there was a correlation between the utilisation of the 7-on-6 strategy and the specific moment of the game. Could the deployment of this tactical strategy, now allowed by the game rules, be predicted based on the game flow or the context of a specific moment in the game? The difference in score was, then, selected as key contextual variable to explore possible strategical reason for employing 7-on-6 in specific game moments. Other authors, such as Gümüş and Gençoğlu (2020a) opted to explore the playing time contextual variable, dividing the total playing time into distinct groups of 10 minutes each, as a means of evaluating the frequency of usage of the 7-on-6 during the course of match. However, their approach did not provide a comprehensive understanding of the playing time influence on the decision to use of the 7-on-6. Most likely as the coach decision to employ it is multifactorial.

The present study revealed that the 7-on-6 employed tended to occur with the greatest frequency in situations where the teams were losing the game (in a more play-by-play analysis type), particularly when the margin was narrow (between -4 and -2 goals), where the goal difference of 6-on-6 showed significantly higher values than 7-on-6 (p-value < .001, $dz = 0.19$) and significantly lower than post 7-on-6 (p-value < .001, $dz = -0.19$). Also, the 7-on-6 were significantly lower than the post 7-on-6 (p-value < .001, $dz = 0.74$). These findings are consistent with those of (Macedo et al., 2024; Maroja et al., 2020), who observed a greater utilisation of the 7-on-6 as a means of attempt to reverse a disadvantage on the scoreboard. Similarly, the study by Prudente et al. (2022) illustrates this tendency, as the Portuguese team employed the 7-on-6 strategy with greater frequency in scenarios where they were facing a deficit or seeking to achieve a tie.

To develop a more nuanced understanding of the circumstances under which 7-on-6 attacks are deployed, it is important to assess their efficacy and

success ratio. The introduction of an additional player in an offensive game play creates the perception that team's superiority will facilitate a higher probability of scoring. In their preliminary research, Gümüş and Gençoğlu (2020a) observed that utilising the additional player resulted in a favourable outcome, as evidenced by an increase in the average number of goals scored, a reduction in the number of missed shots, and a decline in the frequency of technical errors. Nevertheless, this was the only study identified that reported a favourable outcome regarding the utilisation of the 7-on-6. In a subsequent analysis, the authors posits that the inappropriate deployment of the 7-on-6 can result in adverse outcomes (Gümüş & Gençoğlu, 2020a).

In contrast, the deployment of a 7-on-6 strategy was not perceived as a strategic advantage in the other studies. This is evidenced by the findings that it resulted in a lower goal-scoring ratio (Krahenbühl et al., 2019a; Krahenbühl et al., 2021). These findings are supported by the results of the current study, which suggests that the team's utilisation of the 7-on-6 formation was less effective in scoring goals than the other formations. However, we need to be cautious about generalizations, as these situations also include fast break game play, where the expected rate of success is, in fact, much higher than in all other situations.

It is crucial to consider the potential risks associated with the 7-on-6 game play strategy. Although the attacking team has the advantage of an additional player compared to the defence, the attacking team goal it is vulnerable to adverse effects if there are missed shots or passing errors (Gümüş & Gençoğlu, 2020a; Krahenbühl et al., 2019a; Krahenbühl et al., 2021; Macedo et al., 2024). The results did not confirm our expectations, as there was no increase in attacking effectiveness when a team used a 7-on-6 strategy. One area of interest was the post-attack phase following the 7-on-6 strategy. These attacks exhibited a significantly higher percentage of fast transition (34% fast transition in post-7-on-6, compared to 27% in 6-on-6 and 9% in 7-on-6). Furthermore, the post-7-on-6 attacks exhibited a shorter duration (21.22 ± 14.87) and a lower number of completed passes (7.8 ± 6.6).

5.2. Exploring the Effect of Attackers-Defenders Ratio on Offensive and Defensive Pace Dynamics

In recent years, the IHF has identified the need to enhance public the appeal of handball as a sport. This is evidenced by the changes to the rules which have been implemented with the intention of making the game faster, the most notable change was the implementation of the "quick throw-off". It is crucial to understand the pace of the game to comprehend the dynamics of the use of 7-on-6 within the game.

In technical studies published by the IHF itself, it has been demonstrated that in recent years, in men, youth and junior men's championships, the average number of attacks of the top eight teams in the championship has been approximately 55 attacks per game (Landuré et al., 2021, 2023). In current study that the mean number of attacks per team per game was 61.4.

A statistical analysis of the number of goals scored per match in recent editions of the Men's World Cup reveals an average of 60 goals per game (Landuré et al., 2021). In the youth and junior championships, the average number of goals per game was approximately 63 (Landuré et al., 2023). In this study the mean number of goals scored per game was 59.6. This minor discrepancy may be attributable to the fact that the IHF only analysed the outcomes of the eight highest-ranked teams in the competition, in contrast our analysis of games involved all teams, means more diverse range of rankings.

Furthermore, the IHF has employed the duration of each attack as an additional variable to illustrate its concerns regarding the pace of the game. The mean duration of each attack at the most recent Men World Cup was 33.1 seconds, while at the Youth World Cup it was 28.3 seconds and at the Junior World Cup it was 31.7 seconds (Landuré et al., 2021, 2023). We found a mean value of (29.5 ± 19.1) seconds per attack. Furthermore, it was of concern to identify this attack time value across the three different game play configurations. A statistical analysis revealed that there were significant differences between 7-on-6 and 6-on-6 (p-value < .001, dz = 0.11) and between 7-on-6 and post 7-on-6 (p-value < .001, dz = 0.37). No statistical differences were identified between the

6-on-6 and post 7-on-6 formats, although the median value of post 7-on-6 attacks was found to be lower.

The time spent in each game play configuration or game phase (and sub-phases) has not previously been the subject of investigation. This current study explores the duration of each attack and sub-phase. As expected, when a team opted to play 7-on-6, the most time in attack was spent in slow transition for defence to attack, which allowed for all the substitutions to be made, and subsequent positional attack. Furthermore, the duration of the positional attack was longer (24.1 ± 18.9), and the number of passes were also higher, which indicates a slower game. In contrast, the subsequent attack of the defending team facing seven attacking court players was faster-paced, evident not only in the fast transitions but also in the deployment of long-distance shots targeting the empty goal, given the absence of the goalkeeper in the goal.

5.3. Investigating Physical Exertion According to Game Phase and Attackers-Defenders Ratio

In our analysis of studies evaluating the use of the 7-on-6, we observed that most studies focused on notational analyses to assess the effectiveness and efficiency of this strategy. A single study was identified that sought to understand the physical variables associated with the use of the 7-on-6. This involved measuring the external load and heart rate of the players. However, it should be noted that this was conducted in a simulated context, rather than in a real game situation (Gümüş & Gençoğlu, 2020b).

The aim of this study was to investigate the impact of 7-on-6 and its different phases of play on physical exertion, considering variables such as jerk and DSL. Furthermore, Freitas and Estriga (2024) employed these variables to assess the 2022 European U20 Championship matches, with the objective of quantifying and analysing the discrepancies in these variables across the various playing positions. Their study revealed discrepancies in physical activity among the various playing positions. The data indicated that backs exhibited the highest DSL load, followed by wings, line players and goalkeepers. The only observed

difference in match-jerk was between goalkeepers and other positions (Freitas & Estriga, 2024).

In their study, Manchado et al. (2024) attempted to differentiate between attack and defence when evaluating the players' external load data, the results demonstrated that a greater number of accelerations and decelerations were performed by players in the Wings and Centre Back positions throughout the game and in attack, in comparison to players in other positions. In defence, the Wings had the highest values, followed by the Line Players. However, their research also involved analysing the players according to specific positions, as opposed to examining the team, as we do here. In our study, no statistically significant differences were identified in the DSL values between attack and defence. Given that this metric incorporates the fastest actions, our hypothesis was that the DSL would be lower during the 7-on-6 attack in comparison to the other phases of the game.

A statistical analysis of the data revealed that the jerk values during the 7-on-6 phase was higher than the other configurations. It is probable that these values were identified because the entirety of the attacking phase was incorporated into the calculations, including the transition period. As this is still a work in progress, the next step is to carry out the same calculations using Phyton and remove the values from the transition phases. This will enable the observation of the jerk values only during the positional attack of the three different phases of play.

In the defensive phase, the jerk values exerted by the opposing team was greater in a 7-on-6 situation than in a 6-on-6 situation. This is likely due to the defensive team's tendency to become more active when they are at a disadvantage. This may include attempting to steal the ball or forcing their opponents into a mistake, thereby creating an opportunity for a direct shot without the goalkeeper in position.

In terms of total distance covered, both defensively and offensively, there were differences between the 7-on-6 and other gameplay configurations. This could be due to the substitution of the goalkeeper and the greater width of the

attack, which requires players to run toward the bench more frequently to make the necessary substitutions in attack, while defenders may move more around the goal area line. It is interesting to note that no significant differences were observed between the 6-on-6 and the post 7-on-6 periods in the distance covered. This suggests that, as with the total distance covered, the intensity of high-speed runs returns to similar levels because of the long-range shots, or the quick transitions and few players involved in the counter-attack.

Regarding HSR distance in attack, differences were found between the three game configurations. The 7-on-6 format showed lower distances at HSR compared to the 6-on-6 format, which was expected, as players tend to move at a walking pace from defence to attack to set up the 7-on-6 (as substitutions need to be made). In this format, attackers tend to prioritize passes and controlled movements over “explosive” forward runs (or breakthrough moves), given that the opposing team is already organized. Therefore, more time is spent moving up the court, resulting in a longer attacking tempo, a greater number of passes, and a higher jerk value.

In terms of defensive performance, no differences were observed in the distance covered at HSR the three *game* play configurations. This may indicate that defenders maintain a comparable high-speed movement pattern, most likely explained by the need to quickly return to their defensive positions to protect the ball, regardless of the opposing team's attack configuration or methodology

Limitations and ongoing studies

One of the limitations of our study was the synchronization of game events (through notational coding of the games) with positional and inertial data, as this was a novel approach with no precedent in the existing literature applied to handball. Furthermore, the coding process was too time-consuming, which constrained the scope of our investigation and limited the size of our database, or the number of matches studied. This process is still ongoing and is essential to obtain a more comprehensive understanding of the impact and adaptation to the new rules, as well as to identify more robust pace dynamic differences between 6-on-6 and 7-on-6 gameplay, both in defence and attack.

Another related and ongoing work uses the position of the ball on the court (only when possessed by a player), as recorded via LPS. This will allow the measurement of ball passing speed, the level of defensive pressure based on ball positioning, and its effects, such as limiting open passing lanes.

To the knowledge of the researching team, no previous studies have attempted to synchronise the data collected from handball in this way. This approach will allow us to study the effect of a 7-on-6 on the opposing defence, its movement on the court, and whether it occupies a greater area. This would indicate greater pressure from the defence, which could force errors from the attacking team in a 7-on-6. The data will also allow for a comparison of the behaviour of the teams during the 7-on-6 and 6-on-6 positional attacks. Additionally, it will be possible to ascertain whether the observed behaviours during the empty goal, when the attacking team has the numerical advantage, are maintained during the moments in which 2-minute suspension.

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6. Conclusions

The primary objective was to investigate the influence of distinct tactical game play states (i.e., numerical equality, advantage/disadvantage) with and without a goalkeeper protecting the goal on the game pace, exertion, and effectiveness of attacking manoeuvres. As hypothesised, the 7-on-6 game was found to have a markedly slower transition phase in comparison to other game play configurations. Also, notable differences were identified in ball possession duration across the three phases of the game that were analysed. The number of passes exchanged was also found to be higher during 7-on-6 attacks.

The hypothesis that the attack effectiveness would be higher in the 7-on-6 positional game compared to the 6-on-6 positional game was not confirmed, as no differences in the effectiveness in 7-on-6 attacks in comparison to the 6-on-6 positional game was found. The discrepancy in the number of attacks per game play configurations, along with methodologic problems that impede properly sampling.

The hypothesis that the subsequent attack by the defending team, after facing seven attackers (with the opposing team having an empty goal), would be marked by a greater number of fast transitions and a lower number of passes was found to be supported by the evidence. It was observed that the subsequent attack by the defensive team, after facing seven attackers (with the opponent's empty goal), was significantly characterised by a higher number of quick transitions, as well as a shorter attack duration and a lower number of passes.

The hypothesis that the jerk would be lower in the 7-on-6 positional game compared to the 6-on-6 positional game was not confirmed, as no differences in the jerk values during the 7-on-6 phase were observed to exceed those of the other games. It can be reasonably assumed that these values were identified because the entirety of the attacking phase was incorporated into the calculations, including the transition period.

The hypothesis that physical exertion would be lower in the 7-on-6 positional game compared to the 6-on-6 positional game was partially confirmed,

as no differences were found in the DSL. However, this result requires further analysis, as the attacking sequences analyzed include the transition sub-phase. Higher values of jerk and distance covered were found in the 7-on-6 situation, whereas the opposite was observed for the HSR distance.

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