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Cognitive fatigue in tennis. Current understanding and application among Australian high-performance tennis coaches

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This study investigated the understanding and conceptualization of cognitive fatigue in a tennis context and its application among high-performance tennis coaches (HPTC). Semi-structured interviews were conducted with eighteen HPTC in Australia to gather insights into their knowledge of cognitive load and fatigue. Through an interpretive qualitative case study approach, five themes were identified: 'Definitions of cognitive load', 'Definitions of cognitive fatigue', 'Development of cognitive fatigue', 'Management of cognitive fatigue' and 'Perceptions of training to prevent cognitive fatigue'. While coaches demonstrated some awareness of cognitive fatigue in their athletes, variations were observed in the strategies employed to manage and alleviate cognitive fatigue. This study has identified the need for better: 1) coach education on cognitive load and cognitive fatigue, 2) training techniques to ameliorate state cognitive fatigue, 3) measurement tools to track athlete cognitive load and state changes in cognitive fatigue.

KEY WORDS: Training, Match performance, Load, Athletes.

1. Introduction

The ability to withstand varying cognitive loads (e.g., perceived and task-induced) is an important aspect of elite sport performance. Defined as the

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load that a particular task imposes on one's cognitive system (Paas et al., 2003), little is known about predicting individual differences in the effects of cognitive load among athletes. Poor management of cognitive load in the short-term can impair athletic performance and lead to cognitive fatigue over time. However, cognitive fatigue has been under-studied in sport science relative to investigations regarding physical fatigue which have been more prevalent. Due to its multidimensional complexity, the terminology and taxonomy of the construct of cognitive fatigue has been discussed in several papers to determine the best-fit model (Ackerman, 2011; Behrens et al., 2023; Enoka & Duchateau, 2016; Pattyn et al., 2018; Van Cutsem et al., 2017). Enoka and Duchateau (2016) concluded that an appropriate framework should first be made on whether the experienced fatigue is a form of 'trait' (fatigue induced over time) or 'state' (in-the-moment task-induced actual or perceived fatigue) cognitive fatigue. This 'trait' vs 'state' conceptualisation of cognitive fatigue also further enabled a distinction within 'state' cognitive fatigue between objective (performance fatigue) and subjective (perceived fatigue). Behrens et al., (2023) developed this framework further by proposing that "no single factor can determine performance fatigue and perceived fatigue" (p. 18). Accordingly, focus should be on the relative weight of each cause (e.g., task, emotion, environment) and the interaction between them to enable accurate assessment of cognitive fatigue and gain insight into how it may be best ameliorated.

Interviews by Russell et al. (2019a; 2019b) summarised this well; the coaches and support staff interviewed in their study shared a consistent belief that cognitive fatigue affected athlete decision-making, awareness, and quality of movement, yet only athlete self-report was mentioned as a form of quantifying cognitive fatigue. In tennis, it is widely accepted that the mind has a significant impact on a tennis players competitive outcome and longevity in the sport (Crespo & Lubbers, 2015; Mathers, 2017; Weinberg, 1988). However, clear conceptualisations and objective measurements of cognitive fatigue are scarce and, instead, the focus in the literature has primarily been on drills to improve technique and tactile strategies (Gomes et al., 2015; Penalva et al., 2022).

Cognitive fatigue has also been shown to be detrimental to sport-specific skill performance. For instance, it has increased reaction time and decreased accuracy in table tennis athletes (Le Mansec et al., 2018), basketballers (Moreira et al., 2018), cricketers (Veness et al., 2017) and soccer players (Gantois et al., 2020; Smith et al., 2015; Smith et al., 2016). However, cognitive fatigue has been underexplored in tennis. Although cognitive fatigue itself has not yet been considered by researchers, mental skills have; an extensive (n = 153 junior tennis coaches) study by Gould et al. (1999) concluded

that more education was needed for coaches to feel comfortable teaching athletes mental skills such as how to perform under pressure, develop a winning strategy and improve emotional control. Very little is known about how tennis coaches might manage cognitive fatigue in their athletes, or whether targeted mental training might reduce the impact of cognitive fatigue on tennis athletes' performance. Accordingly, the aim of this study was to explore understanding and conceptualisation of cognitive fatigue in a tennis context, and the application of cognitive fatigue research, in a sample of high-performance tennis coaches (HPTCs). It was hypothesised that HPTC may not provide detailed definitions but instead would be able to demonstrate their knowledge from applied examples during training and tournament seasons.

2. Study Design

2.1 Method

This study employed an interpretive qualitative case study approach (Stake, 1995) to gain insights into the knowledge and practices of HPTCs regarding their coaching experience, style, and their understanding of the concepts of cognitive load and fatigue. In interpretive research, knowledge is gained through developing an understanding of the socially constructed nature of reality experienced by the research participants. To achieve this, we explored the participants' habits of interpretation, their social orders of practice, and the culture of their professional environment.

Eighteen HPTCs were recruited from the highest tennis coaching level in Australia. All coaches were currently coaching athletes with an Australian ranking for their age group. To gather a broad group of HPTCs from across Australia, snowball recruitment was utilised (Noy, 2008). There were 12 male and 6 female coaches (average age 42 ± 12 years) from tennis academies in New South Wales, Queensland, and Victoria. The average coaching years was 16 years (min: 1 year, max: 41 years). Data saturation was reached after 18 interviews, once a clear consensus of responses began to appear and no new interpretations were provided by HPTCs, allowing the research question and aim of the study to be answered through the collective responses (Guest et al., 2006).

2.2 Research Method

Following ethical approval (RMIT HREC #23501), email invitations were sent to HPTCs, and interviews were scheduled at a convenient time with those coaches who expressed interest. Before the interview, coaches were asked to read an information sheet and provide their consent to participate. Due to the global pandemic, interviews were conducted online (Davis et al., 2020). A semi-structured interview approach was employed, and interviews were conducted by a single researcher to ensure consistency.

The interviewer followed an interview guide which outlined specific questions in order of themes, such as cognitive load and fatigue (Turner, 2010). The semi-structured constructs allowed the interviewer to follow conversations with coaches exploring their individual know-

ledge, understanding, and implementation of practices (Jones et al., 2004; Turner, 2010). Interviews were digitally recorded (Salmons, 2014) and the file was automatically transcribed and reviewed for errors using Microsoft Office 365 application Microsoft Word (v16.48) on an Apple MacBook Air (2018). The average recorded interview time was 50m 47s ± 17m 49s (range 29m 27s to 96m 5s).

2.3 Data Analysis

Following the guidelines of Braun and Clarke (2012), each interview transcript was systematically reviewed to familiarise the researcher with the responses and to generate initial themes. Themes were listed as they appeared in the data, and then ordered and clustered theoretically to ensure they accurately reflected patterns across the entire data set (Braun & Clarke, 2012). Overarching terms that summarised the nature of each theme were named 'superordinate' themes. Through the annotation of keywords and phrases, selected responses from the HPTCs were used to illustrate key findings and links to the objectives of the study.

3. Results

Initial analysis of data revealed five themes, with each major theme having sub-themes, as shown in Table 1. The data is presented using direct

Table I
Summarises the above states themes and subthemes detailed.
Theme And Sub-Themes Developed From Analysis.

Theme	Sub-themes
Definitions of cognitive load	Inconsistent definition of cognitive load Four levels of understanding cognitive load
Definitions of cognitive fatigue	Inconsistent terminology used. Similar understanding of the theory of cognitive fatigue
Development of cognitive fatigue	Training environment Competition environment External Stressors / Pressure Internal Stressors Individual cognitive thresholds Recognition of cognitive fatigue in an athlete
Management of cognitive fatigue	Conversations with athletes Match routines No strategy
Perceptions of training to prevent cognitive fatigue	Important but underrated. Athlete 'buy-in.' a necessity. More education required. Poor access to, and knowledge of, tennis specific cognitive training programs

quotes from coaches, as well as summaries of longer quotes. Numerical values are used to maintain anonymity of coaches.

3.1 Theme 1: *Definitions Of Cognitive Load*

Coaches' definitions of cognitive load are displayed in Figure 1. In the figure, the frequency of the use of a word is denoted by the size of the text for that word. 'Time' and 'Stress' were two commonly used terms associated with defining cognitive load, followed by 'Matches,' 'Practice,' 'Information Processing' and 'Different' (i.e., that cognitive fatigue is a phenomenon that is experienced differently across athletes).

Further, four levels of understanding became apparent: (1) not able to provide a definition (17%); (2) defined cognitive fatigue as the total mental capacity of an individual (28%); (3) provided an example of a high load men-

Fig. 1. - Word cloud from HPTCs response to 'what is your understanding of cognitive load?

tal task or environment specific to tennis (22%); or (4) provided a layered response which encompassed a high load mental task in tennis, and identification that 'load' and its associated performance impact is relative to the individual's threshold/capacity (33%).

Of the coaches with level 1 understanding, responses varied. For example, one coach provided a definition and then indicated that they did not think it was correct. A second coach simply stated that they did not know, but that they did understand the concept once it was explained to them.

Coaches with level 2 understanding attempted to provide a holistic definition, but it either was unclear or missed an aspect of cognitive load. For example, two coaches described contexts where demands on mental resources may increase but did not define cognitive load in relation to the impact and experience of the athlete (i.e., "I definitely feel that mental load builds throughout practices, matches, competition and, you know, the length of time you might be in competition", P8.1, June 2021). P17 considered that mental load can be experienced over the course of a match, a training session, a conversation, or a tournament, concluding that "it can be dependent on any number of factors" (P17.1, August 2021). In contrast both P16 and P11 discussed pressure as a form of mental load, but did not define the term mental load:

Mental load, I would say that connects to pressure, so what the situation that they're facing is. It might even be a positive mental load, like maybe there's a lot of great things in their environment, but it's just how they perceive their environment I would say is then the load that is on them. I don't know if that answers the question. (P16.1, August 2021).

P11 also referred to replicating match pressure in training (i.e., "... practice pressure; is that the term you're looking for? Mental load is practice pressure", P11.1, August 2021).

Coaches with level 3 understanding described the total mental capacity of an individual and acknowledged that everyone differs in their mental processing capabilities but that this can be context dependent and change over time. For example, P15 defined mental load as:

Mental load, uh. I think it's where you have a lot of information to treat at once. And then, because you've got so many things to think about, then you're not very efficient, to a certain point, you're not very efficient, but after you can do it. You can also be affected by stress. So, stressing about a lot of information, but also like stress because of a final in front of 15,000 people, that can stress you out or also physical stress like maybe lack of oxygen. (P15.1, August 2021).

Coaches with level 4 understanding were able to provide a complete definition of cognitive load, and examples in a tennis context. Although the

coaches in this group provided unique responses, a commonality between the coaches was their ability to draw upon their own research and/or experiences. Some coaches provided anecdotal references to researching the term for their own interests and were eager for research in this field to be developed, as seen in P10's comment: "I think there'd be some real value in exploring that from a scientific perspective, I don't think many people are looking at that" (P10.1, August 2021).

Interestingly, even if unable to articulate a clear definition of cognitive load, all coaches were able to provide anecdotes or examples to illustrate some understanding of cognitive load, or how they would detect the presence of high mental load in their athletes. Detailed as a 'game-based' approach to coaching in the study by Crespo et al. (2004), the natural use of anecdotes to further clarify a point speaks to the nature of coaching itself, and further highlights the high-performance abilities of the coaches interviewed. Understanding the importance of anecdotes and examples in coaching may hold a prominent place in better translating cognitive load and cognitive fatigue concepts from coaches to their players, so knowledge and application becomes more commonplace in Australian tennis.

3.2 Theme 2: *Definitions of Cognitive Fatigue*

The collective understanding and definition of cognitive fatigue is shown in Figure 2. The word cloud illustrates 'Ability,' 'Decision-making,' 'Overloaded' and 'Time' as the most frequently used terms by coaches when they explained their understanding of cognitive fatigue. Of the coaches who used the term throughout the interview, 6% used 'mental fatigue', 39% used 'cognitive fatigue', 11% used both terms interchangeably, and 44% did not directly mention the term in their responses.

Coaches were more confident in their definition of cognitive fatigue, than their definition of cognitive load, and gave succinct responses. For example, "The depletion of mental resources" (P12.2, August 2021).

As with cognitive load, coaches tended to use specific anecdotes related to tennis when explaining their understanding of cognitive fatigue:

They [tennis players] just become overloaded with information and for instance, in this situation with tennis, it can affect what they stand for. So again, you could develop a skill, whether that be technically or tactically. But then when it is overloaded, that can just completely go out the window. I also think as an athlete when they're overloaded, their perception of reality versus what they feel can be quite distorted… in the sense that it can drasti-

Fig. 2. - Word cloud from HPTCs response to 'what is your understanding of cognitive fatigue?'

cally impact their ability to understand and execute the skills that have been developed previously. (P18.1, September 2021).

This sentiment was echoed by several coaches who also identified a lapse in concentration or skill execution when their players became mentally fatigued.

3.3. Theme 3: *Development of Cognitive Fatigue*

All coaches were able to provide an example of external stressors that they believed could contribute towards cognitive fatigue. Most commonly, coaches provided example of task-induced state fatigue. One coach explained that it can be a result of the impact of different coaching styles:

I think a lot of coaches over-coach and give too many instructions… and it just overloads their [athletes] working memory and then you know their

technique suffers because of that and their ability to make better decisions also suffers. (P1.1, February 2021).

Another coach highlighted the role of the competitive environment:

Where I've experienced or seen the most amount of mental fatigue is probably on the road when you're traveling, and all the stresses that come with that heightened emotional responses are going to trigger a greater level of fatigue. And if you accumulate, day after day, week after week, which is sometimes the scenario… that load over time can be quite overwhelming and to the point where it's almost not manageable. (P7.1, June 2021).

Several coaches gave specific examples in relation to the juggling of responsibilities faced by junior players:

I think it's definitely linked to when they have a lot of pressure at school as well as what's going on outside [of tennis], or a lot of pressure from their parents. You can notice that in younger players. (P16.2, August 2021).

Coaches also considered that some causes of cognitive fatigue can be internal stressors, for example anxiety:

Leading up towards big events, they often get a lot stressed out; they start to overthink it and they're losing confidence in what they actually can do, and they start to question their own ability. (P11.2, August 2021).

P9 elaborated on this sentiment stating that anxiety can lead to poor decision-making:

Slower decision-making, so the decisions are almost having to all be individually processed, they're not flowing between each other and it's less of an anticipation... It's more of a just reaction here and there to the balls or to the play. (P9.3, July 2021).

Finally, coaches were also able to determine that cognitive fatigue can appear at different points, or in different environments, and affect players differently, as demonstrated in the quote below:

I think it comes in varying levels for the player, so while one athlete might stop under a certain threshold, another will continue to go beyond that. I think it comes from training; it comes from the experience that you're able to withstand more of a mental threshold... So, I think it depends on the athlete, because some people really like stressful situations, while others steer away from that. (P4.2, June 2021).

3.4. Theme 4: *Management of Cognitive Fatigue*

When coaches were asked about strategies used to help manage high mental loads or periods of cognitive fatigue experienced in their players, the

most common strategy was conversation with their athlete. For example, P5 stated:

I try to be a person that they can actually talk to if things happen at school or things happen at home. And some are gonna open up and some won't open up as much, but I try to create a dialogue where they feel like they can tell me if things go wrong, if they're tired, or if they're stressed... I just try to check on a regular basis, how they're going, where they're struggling, where they feel like they need help. You know, sometimes they might have a very bad session, and I was like 'it seems like you're off today, what's happening, you know you can tell me.' So yeah, I try to understand the person, not just coach the player. (P5.2, June 2021).

P6 provided a unique insight into their experiences working with all levels of national and international tennis players. They had noticed how athletes at different playing levels experience and manage the sensations that can come with being mentally fatigued.

I think the pros learn how to live with it a little bit better and obviously with younger players, at some stage it will happen to them for the first time and when it does happen, they're actually quite bamboozled as to what they need to do. But as they get used to it happening, they learn strategies along the way as to how to deal with it. (P6.2, June 2021).

Coaches also reported that they strategically aimed to replicate match stressors during practice with visualization techniques so that athletes became more familiar with managing stressors during matches. P5 said he used this technique to "basically train them to learn to handle when things go wrong. So, if things go wrong in a match, they're not completely lost". (P5.3, June 2021).

P14 also provided a detailed response on how they teach athletes strategies to use in matches but also strategies that should become a part of individual players techniques. Some strategies identified by this coach included shifting focus externally, reducing heart rate, maintaining a positive mindset, and using cues that have meaning to the individual players. A final strategy mentioned by six coaches was to use a tennis diary as a way for athletes to keep a record of how they were feeling and to reframe situations.

However, some responses indicated that not all coaches (28%) have a clear strategy to specifically manage cognitive load or fatigue.

3.5. Theme 5: *Importance of Training to Prevent Cognitive Fatigue*

The final question that was asked of HPTCs used a rating scale from 0 (not important) to 5 (most important) to understand their own importance

of training the mental aspects of tennis. The average score was a 4.6 ± .54. Generally, responses acknowledged that it is important, but not currently prioritized with the focus being on physical rather than mental training. For example, P5 stated "I think it's the most underrated side of competitive tennis" (P5.4, June 2021). Other coaches reported that training the mental aspects of tennis can be the defining factor in winning or losing at the top levels of tennis.

> If you watched the players who were ranked 100 either side of him (a top-ranked Australian player) you'd struggle to know who was better watching them hit. It's how they decide what to do in a match situation that determines who's the better player. (P6.3, June 2021).
>
> It gets to a point where everybody can hit the ball up and they hit the ball pretty well. So, at the end of the day, it's about who can outthink and out last the other one mentally, you know. (P8.3, June 2021).

However, P1 suggested that mental training may only be impactful if a player is ready for it:

> I think for players who are ready for it, it's a five, players who aren't ready for it, those who don't have the basic technique, I think probably like a one or a two. (P1.4, February 2021).

An interesting comment came from P6, who suggested that players were sometimes not willing to discuss cognitive fatigue, despite the coach already noticing it influencing their play. This sheds some light as to difficulties coaches may have when the athlete doesn't 'buy-in' to the idea or want to engage in discussions on the topic.

> Often, it's one area where I find it's very difficult to get honest answers from players. Players are more than willing to put their hand up for errors that they make but are often unwilling to sort of admit to any mental weakness or nervousness. (P6.1, June 2021).

Finally, education was identified as another important factor in training cognitive fatigue. P5's response acknowledged that they need to be more educated in this area, but also reiterated that their most successful players were the ones with the strongest mental qualities.

> Something I'm not doing enough and I wanna do a lot more, I've been starting to read a lot of books and blogs... I think for me it's the most underrated part of tennis. I think it's the most important part of tennis, and it's the least trained side of tennis. We coaches are great at doing drills, we're great at developing technique, we're great at developing movements, but we're not great at developing the mental aspect, and I see with my players the most successful players by far, are not the most talented, they're the ones that are

mentally stronger than anyone else. They're my best players. They're the ones that go deep into the tournaments. They're just mentally strong and I think that's something that we coaches don't do enough. (P5.5, June 2021).

Additionally, being a 'tennis coach' is now more multidisciplinary, requiring coaches to be educated in other fields, such as sport psychology. As P10 believed "within a lesson any coach should be practicing principles of sports psychology… I think as a coach, you wear a lot of hats". (P10.2, August 2021). However, P5 identified the challenge with this, whereby coaches are not all sufficiently trained in sport psychology. "I think part of it is maybe that we're not trained to do it, because we're not psychologists" (P5.6, June 2021).

4. Discussion

The purpose of this study was to gain insight into the current understandings of HPTCs on the topics of athlete cognitive load and fatigue. Interviews highlighted that HPTCs had some familiarity with the concepts of cognitive load and cognitive fatigue from a practical sense. However, coaches did not provide a consistent and clear definition. There was also variability in HPTCs ability to describe the effects of high cognitive load and cognitive fatigue experienced in their athletes, which indicates that further training in the detection and management of cognitive fatigue in tennis athletes is needed. This would also support the athletes to gain greater self-awareness of their own experiences of cognitive fatigue that can be developed from a young age, as coaches recognised this as being a defining factor for successful performance at high levels. Further, coaches did not clearly articulate a plan for programming tasks that strategically and systematically loaded the mental resources of athletes. Additionally, there was little evidence of specific training to mitigate cognitive fatigue.

4.1 Defining Cognitive Load and Cognitive Fatigue

From the questions relating to HPTCs ability to define cognitive load and cognitive fatigue, there were varying levels of understanding and confidence on the topic. However, it was evident that there was more consistency and greater confidence in responses related to cognitive fatigue than for cognitive load. The collective ease with which coaches responded to cognitive fatigue questions might be linked to their knowledge of physical fatigue and a perception that there is overlap between physical and cognitive fatigue.

Despite this improved knowledge, coaches did not explicitly distinguish between trait or state cognitive fatigue in their responses; most commonly providing answers related to task-induced cognitive fatigue (e.g., P1.1)

The inconsistency in responses between HPTCs highlight a gap in knowledge and expertise in relation to this topic at the highest level, despite coaches identifying the practical importance of these concepts. This may be in part due to a relatively limited body of research on the topic, as well as gaps in the professional development of HPTCs in relation to cognitive load and cognitive fatigue. This presents an opportunity for specific upskilling of coaches in the tennis context. However, it is unclear in the literature if this form of education is also being conducted in other sports. Recommendations from Russell et al. (2019a) suggest this form of upskilling may be necessary in all Australian sports.

Another important finding to emerge was that coaches used the terms 'cognitive fatigue' and 'mental fatigue' interchangeably. The significance of this lies within the literature, where a debate lasting over 100 years exists between researchers regarding the 'correct' definition for the multifaceted phenomenon of cognitive fatigue. Indeed, as suggested by Pattyn et al. (2018), "patchy terminology has created a semantic ambiguity in the field" (p.5). Currently, there is still no singular definition that is widely accepted across fields. In cognitive neurosciences literature, 'cognitive fatigue' is widely accepted (Kok, 2022). In sport science literature, there continues to be a debate. The transactional model proposed by Pattyn et al. (2018) intertwines causes, effects, and subjective response of mental fatigue. Whereas Behrens et al. (2023) proposed that the focus should be on the differences in the weight and interaction of each cause of cognitive fatigue. Perhaps it first needs to be considered whether cognitive fatigue research in sport science literature should deviate from other fields due to environment and participant characterises of athletes, as the highly developed and task-specific cognitive process of elite athletes make them a unique sample relative to the general population when focusing on the effects of sport performance.

The practical result of having a blended definition of these two terms in the literature was reflected in the responses of coaches interviewed in this study, as some coaches used 'cognitive fatigue' throughout the interview whilst others used the term 'mental fatigue' and some used these terms interchangeably. This could in part be attributed to an inconsistency of terms used in research and the influence of the specific field that the research is being conducted, as some coaches discussed reading literature on this topic out of their own desires to improve their coaching abilities. That is, the literature on 'cognitive fatigue' and 'mental fatigue' in sport does not offer much

commentary on how to quantitively distinguish the two terms in a scientific and applied sense; and there is still no quantifiable tool to measure the phenomena.

4.2 Development and Management of Cognitive Fatigue

Coaches could all recognise instances where cognitive fatigue was able to be developed in their athletes. However, although no coach specifically distinguished between 'trait' and 'state' fatigue in their response, examples of both were provided from the interviewed cohort. Examples of state-induced fatigue such as "too many instructions" (P1.1), slower decision-making, and anticipation skills (9.3) were provided. By contrast, school and familial pressure (16.2), as well as doubt leading up to tournaments (11.2), were more relevant to trait cognitive fatigue.

Results further revealed that individual coaching style and beliefs influenced perceptions of the trainability of cognitive capacity, and in-turn athletes' ability to combat cognitive fatigue. Similar findings were reported in Gucciardi et al.'s (2009) interviews with elite Australian football coaches, where coaching philosophy was noted as one of the central characteristics for practices of developing an athlete's mental toughness by coaches. Statements from P6 (6.3) and P8 (8.3) provided evidence that these coaches believed the mental abilities of an athlete could make them a successful tennis player. P6, a coach with over 40 years' experience, also suggested that players were reluctant to discuss cognitive fatigue, despite it influencing their performance (6.1). Whether this lack of communication from athletes is because they do not know how to verbalize their feelings at young ages, or whether they do not recognise the signs, is unknown. There is some evidence that athletes are reluctant to seek help for mental health concerns due to fears of stigmatization or being considered "weak" (Castaldelli-Maia et al., 2019). Coaches who encourage openness and help-seeking behaviours, along with anti-stigma interventions surrounding cognitive fatigue, may reduce these barriers to disclosure.

Further understanding coaches and athletes' opinions on the trainability of mitigating cognitive fatigue would be of interest for future researchers. For instance, future research may include investigations into the roles and responsibilities of key stakeholders in the high-performance team that highlight more than just the coaches' beliefs about these concepts. The responses in our study suggested that coaches have many responsibilities, and that perhaps cognitive load or cognitive fatigue specialisation falls outside their scope of expertise. That is, it might fall under the expertise of a sport

psychologist or skill acquisition specialist. Similar conclusions were reported by Williams and Ford (2009) as they considered the development of Olympic athletes, and the important role skill acquisition can have on developing future Olympians. They noted that employing a skill acquisitionist to develop decision-making and anticipation skills are essential for athletes to reach Olympic podiums. Similar findings in Gould et al.'s (1999) study on mental skills training were also considered by tennis coaches interviewed whereby lack of time, lack of player interest and difficulty evaluating mental skills were labelled as key roadblocks to progress this field of tennis sport science.

These barriers, along with the information-seeking behaviours reported by HPTCs in this study (5.4, 5.5 and 10.2), may suggest that further education for HPTCs and guidance and collaboration from sport psychologists and skill acquisition specialists may prove most fruitful in developing elite tennis players. For example, educating HTPCs on cognitive fatigue including what to look for, and how to manage this in athletes may be required, so that coaches are better equipped to support their athletes' performance and wellbeing in general. Research progressing in this field can further guide coaches, as Russell et al. (2021) reported higher ratings of perceived cognitive fatigue by elite female netballers during international competition compared to during training blocks (e.g. pre-season). This is significant when considering the high demand for travel in elite tennis, and further supports a need for consistent and year-long monitoring of athletes' cognitive loads and cognitive fatigue perceptions.

4.3 No Monitoring, Programming, or Mitigating of Cognitive Fatigue.

Early in the interviews, a pattern began to emerge when coaches were asked 'what strategies do you use to mitigate cognitive fatigue?'; it became clear that monitoring cognitive load and programming to mitigate cognitive fatigue were not specifically being trained (5.2, 6.2). However, this was coupled with another key finding that emerged, which was the interest from coaches to be able to better measure and manage cognitive load and cognitive fatigue in their players. Russell et al. (2019a) made similar conclusions that appropriate structure and use of periodised training, as well as development of athlete's capacity to cope with high cognitive loads, may help to mitigate cognitive fatigue.

Whilst specific drills (e.g., recording changes in reaction time) or training load programs related to building an athlete's cognitive load threshold or cognitive fatigue resilience were not currently in place, coaches did provide

evidence of monitoring athletes cognitive load (5.3). For example, many of the coaches indicated that having conversations is a big part of how they check-in with their athlete's well-being. This was also found in a case-study by Mueller et al. (2018) whereby coaches stated they focused on bodily, motor and behavioural cues from athletes to determine how they would appropriately approach the athlete and their needs in a given moment. The importance of the athlete-coach relationship was again supported by Gucciardi et al. (2009) as a key characteristic of developing the mental toughness of an elite Australian football player.

Furthermore, Ackerman and Kanfer (2009) suggest that training should be tailored to the athletes' cognitive load and cognitive ability, as differences in personality traits influenced the level of cognitive fatigue experienced by individuals. As with physical conditioning, training to improve performance under cognitive load or cognitive fatigue needs to be specific, and the imposed demands must exceed or challenge the athletes' current abilities (Gantois et al., 2020; Van Cutsem et al., 2017). This is achieved in the physical conditioning space by following a periodized training plan (Kovacs, 2007; Murphy et al., 2016). However, coaches do not currently apply the same training load periodization model to challenging the cognitive load threshold. For example, in tennis, athletes could work on sustained and selective attention mental tasks that challenge their current capabilities either alongside their on-court training or within specially designed tennis drills. This should be supported by regular evaluations of their cognitive threshold (commonly measured through electroencephalography) (Russell et al., 2020) akin to testing a maximum repetition lift to measure physical strength changes following resistance training (Kovacs, 2007).

4.4 A Potential Solution to Training and Monitoring Cognitive Loads

However, there are barriers to performing these assessments, such as the time commitment and complexity of employing these protocols on a regular basis. One potential solution to these barriers that has recently emerged within the literature is technological applications that offer low-cost and easily accessible cognitive load training and testing. These products claim to provide a method for monitoring cognitive loads and measuring cognitive fatigue, as well as offering a training tool to improve cognitive fatigue resistance (Barker & Oledzka, 2021; Dallaway et al., 2021).

Barker and Oledzka (2021) found an effective far transfer effect with selective visuospatial executive functions in rugby players with a history of

concussions after four weeks of training with a brain training app, providing an example of improved sensations of trait cognitive fatigue. Additionally, Dallaway et al. (2021) reported significantly improved dynamic rhythmic handgrip performance, prefrontal cortical haemodynamic and mental task scores after six weeks of brain endurance training (BET) compared to physical training alone which also supported changes in state cognitive fatigue measures after using BET technology. These technologies offer an exciting opportunity for athletes and coaches alike, but further research is required, particularly in tennis.

4.5 Limitations

Limitations of the research may lie within the methodology as the findings are restricted to Australian high-performance coaches' views. Not interviewing athletes may have limited the conclusions on whether the findings from these interviews trickle down to the players working with HPTCs and would be a recommendation for future investigation. In addition, including follow-up interviews would have been beneficial to further clarify and develop themes that arose such as coaching philosophy and their belief on the trainability of mental resistance/ cognitive-fatigue resistance.

5. Conclusions

This study has provided insight into HPTCs current perceptions and understandings of cognitive load and cognitive fatigue in tennis athletes. Practically, we recommend that further educating coaches on cognitive load training and cognitive fatigue will not only help coaches but also further educate tennis players in being able to recognise and communicate sensations of cognitive fatigue and periods of high cognitive load. Additionally, we highlight the importance of collaboration between coaches, skill acquisition specialists, and sport psychologists to develop and implement an interdisciplinary approach to better design training programs and support athletes. Finally, more research into cognitive load training and cognitive fatigue is required to discover techniques that can measure cognitive load and reduce experiences of cognitive fatigue. There were many similarities between the present study's findings in Australian tennis and a 1999 study on mental skills training in US-tennis (Gould et al., 1999). It appears a bigger push is needed in research and application to further improve such elements of tennis sport science so that in another 25 years a real change is evident. Opportunities

exist in exploring the use of emerging technologies, such as BET, and further research is required to investigate the applications and efficacy of these tools in sports such as tennis.

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