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**Blue Light as a Performance Enhancer: Impacts on Decision-Making,
Reaction Time and Agility in Field Hockey**

A thesis
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of the requirements for the degree
of
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Abstract

Short-wavelength (blue) light has consistently been shown to enhance alertness and cognitive performance by stimulating intrinsically photosensitive retinal ganglion cells that activate arousal-related brain regions. Despite this mechanistic basis, its application as a pre-performance tool in open-skill team sport remains largely underexamined. Field hockey, which places substantial perceptual-cognitive demands on athletes, requiring rapid decision-making, reactive agility, and perceptual-motor integration under time pressure and physical fatigue, therefore, represents a theoretically appropriate context in which to examine whether these effects translate to applied sports performance.

Chapter One critically reviews the existing literature on the performance demands of field hockey, the physiological and neurological mechanisms underpinning short-wavelength light exposure, and its established effects on alertness, cognitive performance and physical readiness. The review identifies a clear gap in sport-specific evidence, noting that while laboratory-based research consistently supports blue light as an acute cognitive enhancer, its translation to ecologically valid athletic environments, particularly open-skill team sports requiring rapid perceptual cognitive processing, remains largely underexplored.

Chapter Two presents a randomised crossover study investigating the acute effects of blue light exposure on reaction time, reactive agility and change-of-direction performance in eleven competitive field hockey players. Participants were exposed to either short-wavelength blue light (~480nm, 6500K) or a placebo condition for 15 minutes before testing, with performance assessed using a reaction time protocol across four time points, a reactive Y-agility test, and a 505 change-of-direction test, each completed with and without a hockey stick and ball. A small-sided game provided an ecologically valid fatigue stimulus. Blue light had no meaningful effect on change-of-direction performance, consistent with its proposed mechanism of action on cognitively loaded tasks rather than tasks reliant on neuromuscular

capacity. Reactive agility improved significantly within the blue light condition in the without-stick conditions (3.04s to 2.89s, $p = .027$), and reaction time decreased progressively under blue light from baseline through to halftime, associated with a *large* within-condition effect ($d = 0.91$) and a *moderate* between-condition difference at halftime ($d = 0.60$). A near-significant elevation in pre-small-sided game heart rate was also observed under blue light relative to placebo (128 vs. 117 bpm, $p = .051$).

Chapter Three synthesises these findings within the broader literature, arguing that the convergent pattern across reaction time, reactive agility, and pre-exercise heart rate reflects a coherent picture of cortical arousal difficult to attribute to placebo response alone. Key limitations include sample size, absence of neurophysiological measures, and risks of poorly timed evening use of light on melatonin suppression and sleep. Future research should prioritise adequately powered and sex-stratified replication, dose-response investigations, and neurophysiological outcome measures to directly assess the cortical arousal mechanism.

Taken together, this thesis provides preliminary but directionally consistent evidence that blue light exposure can enhance cognitively demanding aspects of field hockey performance, extending a body of evidence largely confined to laboratory settings into a more ecologically valid, sport-specific context and supporting its potential as a simple, accessible pre-performance tool in open-skill team sport.

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List of Abbreviations

ACC – Accident Compensation Corporation

ANOVA – Analysis of variance

BPM – Beats per minute

CI – Confidence Interval

COD – Change of direction

CV – Coefficient of variation

EEG – Electroencephalography

FIH – Fédération Internationale de Hockey (International Hockey Federation)

HREC – Human Research Ethics Committee

ICC – Intraclass correlation coefficient

ipRGCs – Intrinsically photosensitive retinal ganglion cells

LED – Light-emitting diode

RCT – Retinohypothalamic tract

SCN – Suprachiasmatic nucleus

SD – Standard deviation

SSG – Small-sided game

Chapter 1: Introduction and Literature Review

1.1 Background and Rationale

Short-wavelength (blue) light has a well-established role in influencing human physiology by regulating circadian rhythm, enhancing alertness and modulating cognitive performance through non-image-forming visual pathways. In recent years, interest has grown in its potential application as a non-invasive performance enhancer, particularly in environments where rapid decision-making, sustained attention, and fast reaction times are critical. Alongside this, modern athletes are increasingly exposed to artificial blue light through digital devices, Light-emitting diode (LED) lighting, and evening competition schedules, making the investigation of its performance-related effects both timely and practically relevant.

While laboratory-based research has consistently demonstrated that blue light can acutely enhance alertness and aspects of cognitive performance, the translation of these findings into applied sport settings remains limited. Team sports such as field hockey place substantial perceptual-cognitive demands on athletes, requiring rapid integration of visual information, anticipatory decision-making, and agile motor responses under pressure. Understanding whether blue light exposure can meaningfully support these demands in ecologically valid contexts is therefore of growing interest within sports science.

This chapter critically synthesises existing literature on the specific demands of field hockey, physiological and cognitive mechanisms of short-wavelength light, and its effects on cognitive and athletic performance. In doing so, it identifies key gaps in applied, sport-specific research, providing a clear rationale for the current study.

1.2 Performance Demands of Field Hockey

1.2.1 Structure and Overview of Field Hockey

Field hockey is an intermittent, invasion-based sport played between two teams of 11 players on a 91.4m x 55m artificial turf pitch (International Hockey Federation (FIH), 2023; Lord et al., 2022). Matches are structured into four 15-minute quarters, separated by two-minute breaks between the first and second, and third and fourth quarters, with a 5-minute halftime interval. Teams are typically organised into defensive, midfield, and attacking units, with the overarching objective of progressing the ball into the attacking circle to generate scoring opportunities. A goal is awarded only when the ball is played from within the attacking circle and travels completely over the goal line beneath the crossbar (Kawalek & Garsztka, 2013). Consequently, tactical frameworks are designed to maximise circle penetrations while simultaneously restricting opposition access.

The sport is characterised by rapid, continuous transitions between defence and attack, requiring players to rapidly adapt their positioning, tactical role, and motor responses in response to the dynamic game conditions (McGuinness et al., 2019; Sunderland & Edwards, 2017). Performance, therefore, involves a combination of symmetrical locomotor movements (e.g., sprinting and multidirectional running) and asymmetrical, unilateral skill-based actions (e.g., passing, pushing, tackling and shooting) while maintaining control of a hooked stick (James et al., 2021; Kawalek & Garsztka, 2013). Due to right-handed stick regulations, players must use only the flat side of the stick during ball manipulation, reinforcing unilateral technical execution and asymmetrical loading patterns. Over time, these structural and technical constraints promote side-dominant movement strategies and musculoskeletal adaptations, reflecting the inherently asymmetrical yet highly dynamic nature of the sport (Fenety & Kumar, 1992; Krzykała et al., 2018).

1.2.2 Physical and Physiological Demands

Field hockey is a high-intensity, intermittent team sport characterised by repeated bouts of sprinting, rapid accelerations and decelerations, and frequent changes of direction (Lythe & Kilding, 2011; McGuinness et al., 2019). Players typically cover distances ranging from 5 to 7km per match, with a large proportion of performance at moderate-to-high intensities, reflecting the unpredictable and transitional nature of play (Buglione et al., 2013; James et al., 2021; Lythe & Kilding, 2011; McMahon & Kennedy, 2019). Short, explosive actions such as sprinting, tackling, and shooting are interspersed with lower-intensity movements, placing significant demand on both aerobic and anaerobic energy systems (Reilly & Borrie, 1992; Sharma & Kailashiya, 2017). The ability to tolerate and reproduce these high-intensity efforts is therefore central to competitive performance.

As a predominantly lower-body-dominant sport, with explosive actions such as sprinting, jumping, and cutting, field hockey generates substantial concentric and eccentric loading on the lower limbs (Van Jaarsveld, 2020). Lower-limb strength, power and neuromuscular coordination underpin acceleration, deceleration, and rapid directional changes (Bustamante-Garrido et al., 2023; Jones et al., 2009). Effective multidirectional movement depends not only on propulsive force but also on horizontal deceleration capacity, which enables rapid braking and directional transitions while attenuating mechanical stress (Harper et al., 2024). Biomechanical analyses highlight significant eccentric muscle contributions, particularly at the knee and ankle joints, during single-leg braking and re-acceleration phases, emphasising the importance of eccentric strength for change of direction performance (De Wit & Pillay, 2025; Fenety & Kumar, 1992; Mateus et al., 2020).

Additionally, players experience sustained postural stress, frequently adopting a semi-crouched position during dribbling and stick handling (Kawałek & Garsztka, 2013; Krzykała et al., 2018). This posture, characterised by prolonged trunk flexion and rotation, increases

muscular demands on the trunk and lower limbs while reinforcing asymmetrical loading due to unilateral stick use (Fenety & Kumar, 1992). Maintaining this unnatural stance for prolonged periods contributes to cumulative neuromuscular fatigue, further highlighting the sport's reliance on well-developed speed, strength, power and fatigue resistance to sustain performance through match play.

1.2.3 Cognitive and Perceptual-Cognitive Demands

Success in field hockey is not solely determined by physical attributes such as speed, strength, and the capacity of aerobic and anaerobic energy systems, but equally by cognitive factors such as decision-making, reaction time, and agility. Players must make rapid decisions in high-pressure situations, determining when to pass, dribble, or shoot while anticipating the movements of teammates and opponents. Effective decision-making in field hockey relies on cognitive mechanisms, including attentional control and pattern recognition, which enable players to adapt to the sport's fast-paced and dynamic environment (Mann et al., 2007; Starkes, 1998).

Decision-making is a critical component of success in hockey, as it influences a player's ability to process information, anticipate play, and respond to game dynamics effectively. Reaction time dictates how quickly a player can respond to external stimuli such as an opponent's movement, the ball's trajectory or a teammate's positioning (Skala & Zemková, 2022). Faster reaction times enhance the accuracy and efficacy of decision-making, allowing players to execute strategic actions with minimal delay and reducing the risk of being outmanoeuvred (Nuri et al., 2013; Zemková & Hamar, 2017). Attentional processes also play a crucial role in decision-making. Skilled hockey players must dynamically shift between broad and selective attention to track multiple moving stimuli while filtering out irrelevant distractions (Furley and Memmert, 2012). Maintaining attentional focus under pressure enables

players to make precise, tactical choices in real time, ensuring they remain responsive to changes in the game and act effectively (Walton et al., 2018). Agility, closely linked to decision-making, facilitates rapid physical adjustments in response to situational demands (Antara et al., 2023). The ability to change direction instantaneously when faced with an opponent's defensive manoeuvre is a defining trait of elite-level performance, reinforcing the connection between cognitive processing speed and motor execution (Young and Ross, 2015). This rapid adjustment is a direct result of the cognitive and perceptual capabilities developed through practice and experience.

The ability to make quick and effective decisions is essential for optimising performance in field hockey. It enhances adaptability, minimises errors, capitalises on scoring opportunities, and sustains game momentum. Given the sport's constantly evolving nature, players must rapidly assess unfolding scenarios and adapt their strategies accordingly. Adaptability allows players to interpret and integrate new information efficiently, facilitating swift and informed decision-making (Malcolm et al., 2022; Skala & Zemková, 2022). Hesitation or slow decision-making can lead to costly errors, such as turnovers or missed scoring opportunities, which can significantly impact team success (Musculus et al., 2021; Weigel & McCluskey, 2015). Furthermore, elite hockey players exhibit an exceptional ability to recognise and exploit fleeting opportunities, often relying on their cognitive processing speed to initiate well-timed passes, shots, or defensive interventions (Reimer and Martin, 2006). Effective cognitive processing ensures that players can execute these transitions smoothly, sustaining strategic advantages and optimising team cohesion (Zemková & Hamar, 2017). The integration of cognitive processing and physical agility underscores the importance of training approaches that enhance both perceptual-cognitive skills and motor proficiency, ultimately refining decision-making capabilities in field hockey.

1.2.4 Integration of Cognitive and Physical Performance in Field Hockey

Successful performance in field hockey emerges from the continuous interaction between perceptual-cognitive processes and physical execution. Rather than functioning independently, cognitive processes guide movement selection, timing and accuracy, enabling players to respond effectively to the unpredictable and rapidly evolving game. This perception-action coupling allows athletes to interpret environmental cues, anticipate opposition behaviour, and execute appropriate motor responses under time constraints.

As noted above, agility represents a key manifestation of this integration, as it requires both efficient neuromuscular function and the ability to process and respond to external stimuli. In offensive contexts, players must rapidly identify potential opportunities and execute coordinated movements to evade defenders. At the same time, defensively, agility enables players to anticipate attacking patterns and restrict space, potentially forcing turnovers (Young and Ross, 2015). These actions rely not only on physical qualities such as strength, balance, and coordination, but also on cognitive functions including reaction time, attentional control, decision-making, executive function and pattern recognition (Skala & Zemková, 2022; Walton et al., 2018). Disruptions to cognitive functions, such as cognitive fatigue, can impair perceptual processing and response execution and decrease technical precision (Badin et al., 2016; Pageaux & Lepers, 2018; Smith et al., 2016). In field hockey specifically, Malcolm et al. (2022) recruited 37 male and female competitive players (19.7 ± 1.2 years) in a randomised crossover design, assessing cognition at pre-match, half-time and full-time. Working memory, assessed via the Corsi Blocks test, a key substrate of in-game decision-making, declined significantly by full time ($ES = -0.6$ blocks) and was negatively correlated with rising cortisol ($r = -0.314$), indicating that the compounding physiological demands of match play progressively compromised higher-order cognitive function in the latter stages. These illustrate the need for integrated training approaches that develop both mental and physical agility,

ensuring athletes can sustain cognitive performance under the compounding demands of competition.

Training approaches that concurrently target neuromuscular and perceptual-cognitive capacities are therefore essential for optimising sport-specific performance. Strength and plyometric training enhance force production, movement efficiency, and stability, supporting rapid accelerations and directional changes (Krishnan and Rajawadha, 2020; Sinkovic et al., 2023; Spiteri et al., 2015; Vogt et al., 2026). In team sport athletes, such training has been shown to produce meaningful improvements in sprint acceleration and reactive agility performance, with lower limb strength identified as a key mechanical determinant for faster explosive movement (Spiteri et al., 2015). However, evidence that physical training alone transfers to reactive agility remains limited, underscoring the importance of also developing the perceptual-cognitive qualities that underpin open-skill performance. When combined with cognitively demanding tasks, these methods can further improve athletes' ability to execute skilled movements under realistic performance conditions. This integrated development of cognitive and physical capabilities is particularly relevant in field hockey, where success depends on the ability to consistently translate perceptual information into effective motor actions. Together, these components interact to optimise athletes' overall performance, enhance game awareness and support movement efficiency in ways that reduce the risk of injury.

1.3 Short-Wavelength Light: Physiological and Cognitive Mechanisms

1.3.1 Characteristics and Properties of Short-Wavelength Light

Short-wavelength light, commonly referred to as blue light, is part of the visible light spectrum with wavelengths ranging from approximately 380 to 500 nanometres (nm), with

peak biological sensitivity occurring around 460-480 nm (Schmidt et al., 2011; Spitschan, 2019). Compared with longer-wavelength light, such as red or orange light, blue light is characterised by higher energy and the capacity to exert photobiological effects on human physiology (Cajochen et al., 2005). Blue light is naturally emitted by the sun, where it plays a critical role in regulating biological rhythms and promoting wakefulness, but it is increasingly produced by artificial sources such as LED screens, fluorescent lighting and electronic devices (Souman et al., 2018; Touitou et al., 2017; Viola et al., 2008). The widespread adoption of LED technology has significantly increased human exposure to short-wavelength light across both daytime and evening environments, raising important implications for physiological regulation and cognitive functioning (Cho et al., 2015; Prayag et al., 2019). Due to its spectral properties and high biological effectiveness, blue light is particularly influential in activating retinal photoreceptors associated with non-visual pathways, thereby influencing various physiological and psychological functions (Spitschan et al., 2017; Vandewalle et al., 2018).

1.3.2 Retinal Photoreception and Non-Visual Neural Pathways

One of the primary mechanisms through which blue light affects human physiology is its interaction with intrinsically photosensitive retinal ganglion cells (ipRGCs), a specialised class of photoreceptors found in the retina (Gooley et al., 2003). These cells contain a specialised photopigment called melanopsin, which is highly sensitive to blue light, particularly light with wavelengths around 480nm (Provencio et al., 2000). Unlike traditional rods and cones, which are primarily responsible for image-forming vision, ipRGCs play a critical role in non-image-forming photoreception by detecting ambient light intensity and spectral composition (Lucas et al., 2014; Schmidt et al., 2011). Melanopsin exhibits peak sensitivity to blue light at approximately 480 nm, making ipRGCs particularly responsive to short-wavelength light exposure (Berson et al., 2002; Do & Yau, 2010). When activated, these

cells transmit signals via the retinohypothalamic tract (RCT) to several brain regions, most notably the suprachiasmatic nucleus (SCN), which serves as the central circadian pacemaker (Archer et al., 2018; Westland et al., 2017).

Beyond circadian regulation, ipRGC projections extend to additional brain areas involved in alertness, cognition, and emotional regulation, including the thalamus, hypothalamus, and brainstem (Fernandez et al., 2018; Vandewalle et al., 2009). These neural pathways enable short-wavelength light to influence cortical activity and cognitive performance independently of visual perception, demonstrating its broader role as a neuromodulatory stimulus (Brown et al., 2012). Functional neuroimaging studies have shown that blue light exposure increases activation in brain regions associated with attention, executive function, and working memory, highlighting its influence on cognitive processing (Chellappa et al., 2011; Vandewalle et al., 2009). This non-visual photoreceptive system provides the biological foundation through which short-wavelength light can influence both physiological regulation and cognitive performance.

1.3.3 Effects on Circadian Rhythms and Hormonal Regulation

Short-wavelength light plays a central role in regulating circadian rhythms, which are endogenous biological cycles governing sleep-wake patterns, hormonal secretion, and physiological functioning across a 24-hour period (Lucas et al., 2014; Schmidt et al., 2011). Exposure to blue light suppresses the production of melatonin, a hormone produced by the pineal gland that promotes the onset of sleep and regulates circadian timing (Cajochen et al., 2005; Gooley et al., 2011). Melatonin suppression occurs because blue light stimulation of ipRGCs signals the SCN to inhibit pineal gland activity, thereby promoting wakefulness and delaying sleep onset when exposure occurs during evening hours (Archer et al., 2018; Vandewalle et al., 2018). This effect is particularly pronounced with short-wavelength light

compared to longer wavelengths, highlighting its dominant influence on circadian physiology (Brainard et al., 2001).

Conversely, exposure to blue light during daytime or morning hours plays a beneficial role in circadian entrainment by aligning internal biological rhythms with the external light-dark cycle (Khalsa et al., 2003; Souman et al., 2018). Morning exposure enhances wakefulness, increases alertness and improves physiological readiness for cognitive and physical performance (Chellappa et al., 2011). In addition to melatonin regulation, blue light exposure has been shown to influence cortisol secretion, a hormone associated with arousal, stress response, and energy mobilisation (Leproult et al., 2001; Petrowski et al., 2019). These hormonal responses demonstrate the broader endocrine impact of short-wavelength light and highlight its potential to influence performance-relevant physiological states.

1.3.4 Effects on Alertness, Arousal, and Cognitive Performance

In addition to its circadian effects, short-wavelength light has been shown to directly enhance alertness, arousal, and cognitive performance through acute neurophysiological mechanisms (Lockley and Gooley, 2006; Vandewalle et al., 2007). Exposure to blue light increases activity within alertness-related neural networks, including the locus coeruleus and prefrontal cortex, which are critical for attention, executive function and decision making (Fernandez et al., 2018; Vandewalle et al., 2009). These neural effects are associated with increased cortical arousal, improved vigilance and enhanced reaction time, particularly during tasks requiring sustained attention and rapid information processing. Chellappa et al. (2011) demonstrated that blue-enriched light significantly improved sustained attention and psychomotor vigilance task performance compared to standard white light, with participants showing faster and more consistent responses across a prolonged testing period. Similarly, Alkozei et al. (2016) reported that acute blue light exposure produced significant reductions in

reaction time and improvements in alertness, with effects emerging within 30 minutes of exposure onset and persisting for over 40 minutes beyond the cessation of exposure. Importantly, these cognitive benefits can occur independently of circadian phase, indicating that blue light can exert immediate performance-enhancing effects regardless of the time of day at which it is administered.

Experimental research has demonstrated that exposure to short-wavelength light improves measures of attention, working memory, and psychomotor performance compared to longer-wavelength light or dim light conditions (Lok et al., 2018; Viola et al., 2008). Improvements in reaction time and decision-making are particularly relevant in high-performance environments such as sport, where rapid cognitive processing is essential for successful performance (Holzman, 2010). Furthermore, blue light exposure has been associated with improved mood, reduced subjective sleepiness, and enhanced perceived alertness, all of which contribute to improved cognitive and behavioural functioning (Chellappa et al., 2014; Prayag et al., 2019; Viola et al., 2008). These findings highlight the potential of short-wavelength light as a non-invasive intervention to enhance cognitive readiness and performance in athletic contexts.

1.4 Exposure to Short-Wavelength Light in Modern Environments

1.4.1 Sources of Short-Wavelength Light

Short-wavelength light is naturally present in sunlight, which represents the primary environmental source and plays a fundamental role in physiological and circadian processes (Cougnard-Gregoire et al., 2023; Prayag et al., 2019). However, unlike natural light exposure, which follows predictable diurnal patterns and decreases after sunset (Cougnard-Gregoire et al., 2023), modern environments expose individuals to artificial sources of blue-enriched light

throughout the day and evening. The widespread use of digital devices, including smartphones, laptops, and tablets, has substantially increased daily exposure to short-wavelength light, as these devices emit biologically active wavelengths at close viewing distances (Chang et al., 2015; O'Hagan & Smith, 2016). This increase in screen time, driven by occupational, educational, and recreational demands, has resulted in prolonged and often mistimed exposure relative to natural circadian rhythms. Light-emitting diode (LED) lighting has become the dominant lighting technology in homes, workplaces, and sports facilities due to its energy efficiency and brightness (O'Hagan and Smith, 2016). These LEDs emit a proportionally greater amount of short-wavelength light than traditional lighting technologies, further contributing to cumulative exposure (Lucas et al., 2014).

Sporting environments themselves also contribute to exposure, as indoor training facilities and stadium floodlights frequently use high-intensity LED systems designed to maximise visual clarity and performance (Spitschan et al., 2017). Consequently, individuals, and particularly athletes, are exposed to short-wavelength light across multiple contexts and throughout the day, extending beyond natural daylight exposure patterns. While appropriate daytime exposure plays an essential role in promoting alertness and circadian regulation, excessive or prolonged exposure, particularly from artificial sources during evening hours, has raised concerns regarding its potential impact on sleep, ocular health, and broader physiological functioning (Prayag et al., 2019). As reliance on digital technology and artificial lighting continues to increase, short-wavelength light exposure has become an increasingly significant environmental factor influencing human biological function, highlighting the importance of understanding its effects within both general and athletic populations.

1.4.2 Prevalence and Patterns of Exposure

Modern behavioural patterns have substantially altered the timing and duration of short-wavelength light exposure, particularly through increased use of digital devices during evening hours, extending artificial light exposure well beyond the boundaries of the natural light-dark cycle (Touitou et al., 2017). Surveys indicate that the majority of young adults engage with screen-based devices immediately preceding sleep, resulting in delayed circadian timing and reduced sleep duration (Exelmans & Van den Bulck, 2016). This shift is particularly relevant for athletes, whose training schedules, competitions, travel demands, and performance analysis often require device use during evening hours (Lastella et al., 2015).

Importantly, exposure patterns are not limited to nighttime use. Athletes may also experience substantial short-wavelength light exposure during daytime training sessions, strength and conditioning programs, and indoor competition environments (Walsh et al., 2021). These altered exposure patterns can influence physiological and cognitive state by modulating alertness and arousal throughout the day, in both training and competition (Souman et al., 2018). Consequently, modern exposure patterns differ substantially from the natural lighting environments under which human physiological systems evolved and highlight the importance of understanding light exposure as a functional environmental factor influencing physiological and cognitive functioning.

1.4.3 Implications for Athletic Populations

The widespread presence of short-wavelength light in athletic environments presents both practical considerations and potential opportunities for performance optimisation. Controlled exposure to blue-enriched light has been shown to enhance alertness, vigilance, and cognitive performance, which may improve attentional processes, reaction speed and perceptual readiness immediately before training or competition (Chellappa et al., 2011; Lok

et al., 2018). These effects are particularly relevant in sports such as field hockey, where athletes must rapidly interpret visual information, make time-critical decisions, and execute precise motor responses under dynamic conditions. However, excessive or poorly timed exposure, particularly during evening hours, may negatively affect sleep quality and duration, which are essential for cognitive functioning, physiological recovery, and subsequent performance (Fullagar et al., 2015; Walsh et al., 2021). Sleep disruption has been associated with impairments in reaction time, decision-making, and overall athletic performance, highlighting the importance of maintaining optimal circadian regulation in athletes (Walsh et al., 2021). Therefore, understanding the timing and context of short-wavelength light exposure is critical for identifying strategies that maximise its potential performance-enhancing benefits while minimising negative effects on recovery and performance readiness.

1.5 Effects of Short-Wavelength Light on Human Performance

1.5.1 Effects on Cognitive Performance

A substantial body of research has examined the cognitive effects of blue light, with consistent evidence supporting its significant role in enhancing attention, reaction time, alertness and executive function. As previously stated, these effects are mediated through projections to the SCN of the hypothalamus via melanopsin-containing ipRGCs, which influence neural pathways involved in arousal regulation and cognitive processing independently of visual perception (Cajochen et al., 2005; Tonetti & Natale, 2019; Vandewalle et al., 2007). Exposure to blue light has consistently been shown to suppress melatonin secretion (Cajochen et al., 2005), trigger phase shifts in circadian timing (Geerdink et al., 2016), and increase alertness and core body temperature (Revell et al., 2006; Tonetti & Natale,

2019). These physiological effects underpin observed improvements in cognitive performance, particularly under conditions of reduced circadian arousal.

Numerous studies have demonstrated that blue light exposure can enhance sustained attention and speed up reaction time (Bansal et al., 2017). Chellappa et al. (2011), for instance, showed that evening exposure to 6500K blue-enriched light improved sustained attention during Psychomotor Vigilance and Go/NO-GO tasks, alongside greater melatonin suppression and heightened alertness. Similarly, Beaven and Ekström (2013) found that blue light significantly improved reaction speed and decision-making accuracy, particularly in tasks involving cognitive interference. Notably, blue light outperformed caffeine in these measures, suggesting that blue light may be particularly effective in high-demand scenarios requiring fast, focused responses.

The specific wavelength of light is also critical. Revell et al. (2006) reported that 470 nm light was more effective than longer wavelengths in increasing subjective alertness, and that even shorter wavelengths (420 nm) produced greater improvements. This wavelength-dependent sensitivity highlights the functional specificity of blue light in modulating neural pathways associated with vigilance and alertness. Neuroimaging has further demonstrated that short-wavelength light increases activation in brain regions associated with attention, working memory, and executive control, including the prefrontal cortex and thalamus (Chellappa et al., 2014; Vandewalle et al., 2007). Overall, the existing literature consistently supports the view that blue light facilitates improvements in cognitive performance, particularly attention and reaction time, through its alerting effects and regulation of circadian rhythm. These findings hold important implications for environments requiring optimal cognitive functioning during periods when natural alertness may be reduced.

1.5.2 Effects on Physical Performance

While the effects of short-wavelength light on cognitive performance are well established, emerging research suggests that blue light exposure may also influence aspects of physical performance indirectly through its effect on physiological arousal and neuromuscular function (Cajochen, 2007; Silvani et al., 2022). Exposure to blue-enriched light has been shown to increase physiological activation, including elevated heart rate, core-body temperature, and sympathetic nervous system activity, all of which are associated with enhanced physical readiness (Cajochen, 2007; Chellappa et al., 2011). These physiological changes may contribute to improved neuromuscular performance, particularly in tasks requiring rapid motor responses.

Studies have demonstrated that acute exposure to blue-enriched light can improve motor response speed and reduce latency, which are critical components of performance in dynamic environments (Souman et al., 2018). Additionally, improvements in alertness and neural activation may enhance motor unit recruitment and coordination, supporting faster and more efficient movement execution (Vandewalle et al., 2018). Increased alertness and arousal resulting from these neuroendocrine changes contribute to improved reaction time, attention and overall cognitive-motor performance (Beaven et al., 2024; Sirayder et al., 2025; Smolders & de Kort, 2014).

These effects have been observed across a range of performance contexts, from laboratory-based psychomotor tasks to applied settings involving physical response demands, with blue light-induced arousal shown to correlate with improvement in both movement speed and dynamic balance under fatigue (Beaven et al., 2024; Sirayder et al., 2025). Furthermore, enhanced neural activation may improve sensory processing and motor response speed, supporting faster and more accurate responses to environmental stimuli (Vandewalle et al., 2018). These mechanisms demonstrate that short-wavelength light exposure enhances

performance primarily through central nervous system activation, improved cognitive processing, and optimised physiological readiness, rather than direct effects on muscular functions. Although blue light does not directly increase muscular strength or aerobic capacity, its effects on neural activation and cognitive-motor integration may contribute to improved performance in tasks requiring speed, coordination, and rapid responses to external stimuli (Prayag et al., 2019).

1.5.3 Implications of Short-Wavelength Light Exposure for Sport-Specific Performance

The cognitive and physiological effects of short-wavelength light exposure have important implications for sport-specific performance, particularly in open-skill sports that require rapid perceptual processing and decision-making. In sports such as field hockey, athletes must operate in a dynamic and cognitively demanding environment, where they are continuously required to assess shifting game scenarios, make rapid strategic decisions, and maintain high levels of physical agility. Reaction time is recognised as a fundamental perceptual-cognitive quality in open-skill sports, with evidence suggesting that athletes in these domains also demonstrate superior anticipatory skills compared to their closed-skill counterparts (Nuri et al., 2013). Emerging evidence further suggests that blue light exposure may enhance these capacities by directly increasing cortical arousal and accelerating neural processing speed (Alkozei et al., 2016; Beaven and Ekström, 2013).

Research has shown that enhanced alertness and cognitive readiness can improve visuomotor performance, decision-making accuracy, and response speed in athletic populations (Silvani et al., 2022). These cognitive benefits are particularly relevant in high-intensity, fast-paced sports such as field hockey, where athletes must rapidly process visual information, anticipate opponents' actions, and execute precise motor responses under pressure (Mori et al.,

2002; Vaeyens et al., 2007). Blue light exposure may support these sport-specific demands by enhancing cognitive performance, particularly during evening training sessions and competitions in field hockey, when athletes may be functioning out of their peak circadian performance window (Reilly & Waterhouse, 2009; Sargent et al., 2014).

Fluctuations in physiological functions such as core body temperature, alertness, and hormonal secretion throughout the day are known to impact athletic performance (Revell et al., 2006). Specifically, performance tends to peak in the late afternoon or early evening, influenced by both internal circadian rhythms and external environmental factors. However, athletes often compete or train outside this window, potentially experiencing diminished cognitive and physical readiness. Research has shown that exposure to bright light, especially blue light, can shift or reset circadian rhythms (Khalsa et al., 2003), reduce melatonin levels (Cajochen, 2007), and increase subjective alertness (Daurat et al., 2000). As a result, blue light may help to mitigate the time-of-day-related decline in performance by enhancing alertness and responsiveness during evening activities. From a practical standpoint, blue light offers a novel tool to support performance during periods when cognitive fatigue might impair an athlete's ability to effectively process environmental stimuli. This is particularly relevant for field hockey players who often compete under artificial lighting conditions or during evening hours.

Improvements in reaction time following blue light exposure have also been associated with enhancements in sprint performance and agility (Tonnessen et al., 2012; Uchida et al., 2013), both of which are essential in team-based sports requiring rapid changes in direction and pace. Furthermore, blue light may play a preventive role by enhancing situational awareness and thus reducing injury risk. Athletes who are more cognitively alert and responsive to their surroundings may be better able to avoid collisions or maladaptive movement patterns that contribute to injury (Silvani et al., 2022). Also, enhanced reaction time following blue light exposure may, in turn, facilitate rapid ball interception or passing decisions. However, this has

yet to be directly validated. While blue light is not expected to directly enhance physical attributes such as strength or endurance, its role in optimising mental processes involved in recognising opportunities, making decisions, and executing strategies offers a valuable addition to traditional training strategies.

Despite these promising outcomes, careful consideration must be given to the timing and intensity of blue light exposure. Prolonged or poorly timed use, particularly close to bedtime, can disrupt sleep patterns and recovery by interfering with melatonin secretion (Lastella et al., 2015). Given the critical role of sleep for physical and cognitive recovery in athletes, blue light interventions must be strategically implemented to maximise performance benefits while mitigating potential adverse effects on recovery.

1.6 Limitations and Gaps in the Current Literature

While research on the cognitive benefits of blue light has expanded, there are still several notable gaps in the literature. Most existing studies have been conducted in controlled laboratory settings using non-athletic populations, which, while providing valuable insights into underlying physiological and neurocognitive mechanisms, limits their ecological validity and the transferability of findings to the complex, dynamic nature of real-world sport performance. The few studies with sport relevance, including demonstrations that blue light improves reaction speed and dynamic balance under fatigue (Beaven & Ekström, 2013; Silvani et al., 2022), have not used an athletic population or sport-specific tasks. Where studies have been conducted with athletic populations, these have predominantly examined endurance performance or the negative effects of mistimed evening exposure on sleep and recovery (Knaier et al., 2017; Souissi et al., 2025), with very limited evidence examining blue light as a pre-performance intervention in open-skill sport contexts.

Together, studies establishing reaction time and anticipatory skills as fundamental to open-skill sport (Nuri et al., 2013) and demonstrating that competitive match play progressively impairs working memory in field hockey players (Malcolm et al., 2022) collectively build a theoretical case for blue light's potential in sport, yet none directly test it. This limitation is particularly relevant for field-based team sports such as field hockey, which requires athletes to integrate perceptual, cognitive and physical skills, such as decision-making, visual-motor coordination, and reactive agility, simultaneously under time pressure and in unpredictable conditions. Furthermore, the majority of research has been focused on general cognitive outcomes, rather than sport-specific performance measures such as reaction time, reactive agility and decision speed under conditions of fatigue. These sport-relevant metrics are critical determinants of success in team sports but remain understudied in the context of blue-light exposure.

1.7 Research Questions

The preceding review has identified a clear gap in sport-specific evidence for the cognitive performance effects of short-wavelength light. To address this, the present study will examine two primary research questions:

- 1) whether blue light exposure improves reaction time and decision-making performance in competitive field hockey players, and
- 2) whether blue light enhances reactive agility and sport-specific physical performance under ecologically valid conditions.

In pursuing these questions, the study will also seek to assess whether cognitive benefits documented in laboratory settings translate meaningfully into real-world sporting environments. Based on the existing literature, it is hypothesised that blue light will produce

improvements in reaction time, relative to a placebo condition, consistent with the cortical arousal mechanism outlined in this review. It is further hypothesised that these benefits will be specific to open-skilled tasks requiring rapid perceptual-cognitive processing, such as reactive agility, and absent on closed-skilled, pre-planned tasks that are more reliant on neuromuscular capabilities.

1.8 Conclusion

The current body of literature suggests that blue light has the potential to enhance cognitive performance in sport settings, particularly in domains such as reaction time, attention, and reactive agility. Underpinning these effects are well-established neurophysiological pathways, whereby short-wavelength light stimulates ipRGCs, activating the locus coeruleus and prefrontal cortex to increase cortical arousal and accelerate perceptual processing speed. Of particular relevance is the potential for these enhancements during periods of low circadian alertness, such as evening competitions, when cognitive performance may otherwise be compromised by insufficient arousal. For sports like field hockey, which demand continuous fast-paced decision-making, reactive agility, and perceptual-motor integration under time pressure and physical fatigue, the ability to sustain cognitive readiness across the duration of a match is critical to competitive success. As a low-cost, non-invasive intervention, blue light offers a means of acutely elevating alertness and neural efficiency at strategically targeted time points, suggesting its potential as a practical tool for optimising the cognitive qualities most central to sport-specific performance. Whether these laboratory-demonstrated benefits translate into meaningful improvements in ecologically valid sports environments, however, remains an important and largely unresolved question, and one that the present study directly seeks to address.

Chapter 2: Study

2. Abstract

Background: Short-wavelength light enhances alertness and cognitive performance by stimulating light-sensitive retinal cells that influence brain regions responsible for attention and arousal. While these effects are established in laboratory settings, limited research has explored their application in sport-specific contexts. This study investigated whether blue light exposure improves reaction time, decision-making, and agility in competitive field hockey players.

Methods: Eleven competitive field hockey players (5 male, 6 female) completed two sessions in a randomised crossover design. Participants were exposed to either blue light-emitting lamps (6500 K) or a placebo (natural lighting) for 15 minutes before testing. Each session included a reaction time assessment at four time points (baseline, pre-, mid-, and post-small-sided game), a reactive Y-agility test and a 505 change-of-direction (COD) test, each performed with and without a hockey stick and ball. **Results:** Blue light did not significantly affect the COD performance in either equipment condition (without stick: $d = -0.33$; with stick: $d = -0.01$).

Reactive agility improved significantly within the blue light condition without a stick (3.04 to 2.89s, $p = .027$), though the condition $\times$ time interaction was non-significant ($p = .790$).

Reaction time decreased progressively under blue light, with a large within-condition reduction from baseline to halftime ($p = .002$, $d = 0.91$, 95% CI ± 0.47) and a moderate between-condition effect at halftime ($p = .117$, $d = 0.60$, 95% CI ± 0.78). A near-significant pre-exercise heart rate elevation was also observed under blue light relative to placebo (128 vs 117 bpm, $p = .051$, $d = 0.59$).

Discussion: These findings suggest blue light may enhance cognitively demanding aspects of field hockey performance, particularly reactive agility and processing speed, consistent with the proposed cortical arousal mechanism. However, the absence of significant interaction effects and the sample size limit causal conclusions. Building on existing research,

this study highlights blue light's potential for practical use before training, halftime or competition, and provides a foundation for future research with larger sample sizes.

Conclusion: Blue light exposure shows preliminary promise as a practical and transferable tool for enhancing cognitive readiness in high-performance environments.

Key words: blue light, decision-making, agility, field hockey, reaction time

2.1 Introduction

High-performance sport is increasingly characterised by the search for marginal gains that can offer a competitive edge. For athletes in dynamic, open-skill sports such as field hockey, performance depends not only on physical capabilities but also on the ability to rapidly process information and make effective decisions under pressure. These athletes operate in constantly changing environments that demand swift interpretation of visual and auditory stimuli, anticipation of opponents' actions, and immediate execution of context-appropriate motor responses (Klostermann et al., 2020). These perceptual-cognitive skills are crucial during fast-paced transitions and complex tactical play, where milliseconds can separate success from failure (Furley & Memmert, 2012; Zemková & Hamar, 2017).

While physical conditioning and technical skills remain cornerstones of performance training, there is growing recognition of the importance of perceptual-cognitive skills such as reaction time, attention, and decision making (Furley & Memmert, 2012; Zemková & Hamar, 2017). However, these cognitive components are often underemphasised in traditional training programs. Much of the existing literature in this area has relied on laboratory-based tasks that do not reflect the time pressure, uncertainty, and spatial constraints found in actual competition (Mann et al., 2007). This disconnect between research and reality limits the application of existing findings to performance enhancement in real-world sporting environments.

Addressing this issue requires interventions that are both evidence-based and ecologically valid. One promising area of research lies in the use of short-wavelength (blue) light as an acute cognitive enhancer. Studies from chronobiology and neuropsychology have shown that blue light activates intrinsically photosensitive retinal ganglion cells (ipRGCs), which in turn stimulate regions of the brain associated with alertness, arousal, and executive function (Cajochen et al., 2005; Vandewalle et al., 2007). These responses are known to improve attention, vigilance and processing speed, outcomes directly relevant to athletic

performance, particularly in cognitively demanding settings (Beaven & Ekström, 2013; Chellappa et al., 2011).

Although blue light exposure has demonstrated beneficial effects on reaction time and cognitive control in non-athletic populations, its application within sport-specific contexts remains relatively unexplored. Very few studies have examined whether these benefits translate to improvements in performance during real-time decision-making or physically demanding, fast-paced tasks (Beaven & Ekström, 2013; Malcolm et al., 2022; Silvani et al., 2022). Therefore, this study aims to investigate the effects of short-wavelength (blue) light on decision-making and physical performance in competitive field hockey players. Specifically, it will examine whether exposure to blue light enhances reaction time and agility during hockey-specific tasks. It is hypothesised that exposure to blue light will significantly improve reaction time and agility compared to a placebo condition. In doing so, this study seeks to bridge the gap between laboratory-based evidence and applied sport performance, contributing timely and ecologically grounded insight into the potential of blue light as a practical tool for optimising cognitive readiness in competitive field hockey.

2.2 Methodology

2.2.1 Research Design

This study used a randomised, crossover experimental design to investigate the acute effects of short-wavelength (blue) light exposure on decision-making, reaction time and agility in field hockey players. Each participant completed two testing sessions under different conditions: one involving blue light exposure and one placebo condition. The sessions were spaced one week apart to minimise potential carry-over effects. Testing was conducted on a

synthetic field hockey turf to maximise ecological validity and support the translation of findings to real-world sport performance contexts.

In the blue light condition, participants were exposed to short-wavelength light (~480 nm) for 15 minutes, delivered via four commercially available lamps, with 8W Osram 6500 K light bulbs, positioned evenly in the corners of the changing room to ensure uniform ambient illumination. During the exposure period, participants completed an ACC-adapted warm-up to replicate pre-training activity while remaining in the light environment. The placebo condition used an identical changing room next door without the lamps. The only source of minimal natural light entered through a small upper window fitted with textured obscure glass, which diffused incoming light. Sessions were completed at the same time in the evening to control for circadian influences and reduce natural light variability, ensuring consistent biorhythm across the sessions.

2.2.2 Participants

Eleven competitive field hockey players (5 males and 6 females) aged between 18 and 35 years ($M = 26.5$ yrs, $SD = 4.5$ yrs) were recruited from clubs affiliated with the Waikato Hockey Association, with the majority representing the University of Waikato Varsity Hockey Club. There was an equal distribution of primary playing positions, with participants identifying as predominantly defensive or attacking players (midfielders or strikers). All participants had a minimum of three years of competitive playing experience ($M = 16.7$ yrs, $SD = 5.1$ yrs) and were free from injury for at least six weeks before the commencement of testing.

An a priori sample size calculation was conducted to detect a moderate two-tailed effect size ($d = 0.60$) between paired means, consistent with the effect size reported in comparable blue light and cognitive performance research. With 80% power ($\beta = 0.20$) and a 5% statistical

significance level ($\alpha = 0.05$), a minimum of 23 participants were required. Due to practical recruitment constraints, the study aimed to recruit 20 participants; however, a final sample size of 11 was obtained following participant withdrawal and failure to attend scheduled testing sessions.

2.2.3 Eligibility Criteria and Selection Process

Participants were recruited via email announcements, social media posts, word of mouth, and sharing by others, primarily distributed through the University of Waikato's Varsity Hockey Club. Recruitment was initially limited to Varsity members only; however, due to availability issues leading to lower than anticipated numbers, it was expanded to include additional clubs within the Waikato Hockey Association. This expansion was conducted with appropriate approval and consultation with the Association, which provided access to facilities only and had no involvement in study design, data collection, or analysis.

Inclusion criteria required participants to be current hockey club members, aged 18 to 35 years, and regularly engaged in structured training and matches. Exclusion criteria included a history of recent concussion, diagnosed photosensitivity, uncorrected visual impairments, or any neurological disorder, particularly those that could be adversely affected by light exposure.

Initial approval was obtained from the club president to ensure the study aligned with team schedules and permitted access to participants and facilities. Interested individuals received a participant information sheet outlining the study's aims, procedures and time commitment. Those who agreed to participate signed a consent form and completed a pre-participation health questionnaire to confirm their eligibility and suitability for physical testing. Testing times were scheduled in the evening to suit participant availability and to minimise potential confounding effects of natural sunlight, thereby replicating a typical evening training session or match.

2.2.4 Ethical Considerations

Ethical approval was granted by the Human Research Ethics Committee (HREC) at the University of Waikato (HREC(Health)2025#58). All procedures were conducted in accordance with the Ethical Conduct in Human Research and Related Activities Regulations at the University, which emphasise voluntary participation, informed consent, confidentiality, and the right to withdraw at any time without penalty. Participants were fully informed about the study, given opportunities to ask questions, and provided written consent before taking part. The protocol and analysis plan were pre-registered to promote transparency and reproducibility.

2.2.5 Experimental procedure

Each participant attended two testing sessions, spaced one week apart. Upon arrival at each session, participants completed a warm-up before being randomly allocated into two groups to complete the performance assessments. The order of conditions was counterbalanced across participants to reduce order effects. Groups rotated through the two on-field performance tests and then completed the reaction time test in the changing room environment, serving as baseline data. All participants were familiarised with the testing procedures before formal data collection began to minimise learning effects and improve reliability.

Participants were then exposed to either short-wavelength (blue) light or a placebo condition for 15 minutes in the changing rooms, delivered via lamps positioned around the room. During this exposure period, participants in both conditions completed an ACC-adapted warm-up. Immediately following the exposure period, reaction time was reassessed before participants repeated the performance assessments completed in the same order as earlier in the session.

The session concluded with a small-sided game consisting of two 10-minute halves separated by a 5-minute half-time interval, designed to replicate the demands of a typical field

hockey playing environment. Additional reaction time measurements were collected at halftime and at full-time to assess response under increasing levels of fatigue. Each session, including warm-up, exposure, performance testing, gameplay, and cooldown, lasted approximately 90 minutes.

2.2.5.1 Reaction Time Test

A Reaction Time Test was used to assess visual-motor response speed across different levels of fatigue. Six BlazePod units (BlazePod Ltd., Tel Aviv, Israel) were arranged in a semicircular pattern on a standard-height table in front of the participant, spaced approximately 10 cm apart. BlazePods™ are wireless, touch-sensitive light pods controlled via a compatible smartphone application. Participants were seated in a ready position at a comfortable arm's reach from the pods and instructed to tap each pod as it illuminated red, with pods activating in a randomised sequence across a 30-second trial. The BlazePod™ system has demonstrated good test-retest reliability for assessing visual-motor response speed, with intraclass correlation coefficients ranging from 0.785 to 0.833 for simple and complex reaction tasks (De Oliveira et al., 2021; Polechoński et al., 2025). Concurrent validity has also been established, with BlazePod™ reaction speed scores showing strong correlations ($r = 0.640-0.703$) with established computer-based reaction time measures (Çekok & Anaforoğlu, 2025; Polechoński et al., 2025). The test was completed at four time points: Baseline, pre-game, at halftime, and following a small-sided game. Outcome measures included total lights deactivated and average reaction time (milliseconds).

2.2.5.2 Reactive Agility Test

The Reactive Agility Test assessed on-field decision-making and directional speed. A Y-shaped configuration was constructed using Swift™ dual-beam tripod-mounted wireless

timing gates, with gates positioned at the start, decision point, and each of the outer branches, spaced five metres apart (Figure 1). Participants began at the base of the Y in a ready position and sprinted toward the decision gate. Once the beam was broken, a randomly activated outer light illuminated ahead of them, requiring participants to react and change direction as quickly as possible toward the indicated side. The test was first completed with and without a hockey stick and ball, with participants performing two trials. Testing with a hockey stick and ball required the participants to complete the same movement pattern while maintaining ball control during the reactive change of direction. Timing commenced when the beam was broken and stopped when the final gate was cleared. The fastest of two trials was recorded in each condition, with a one-minute rest period provided between trials.

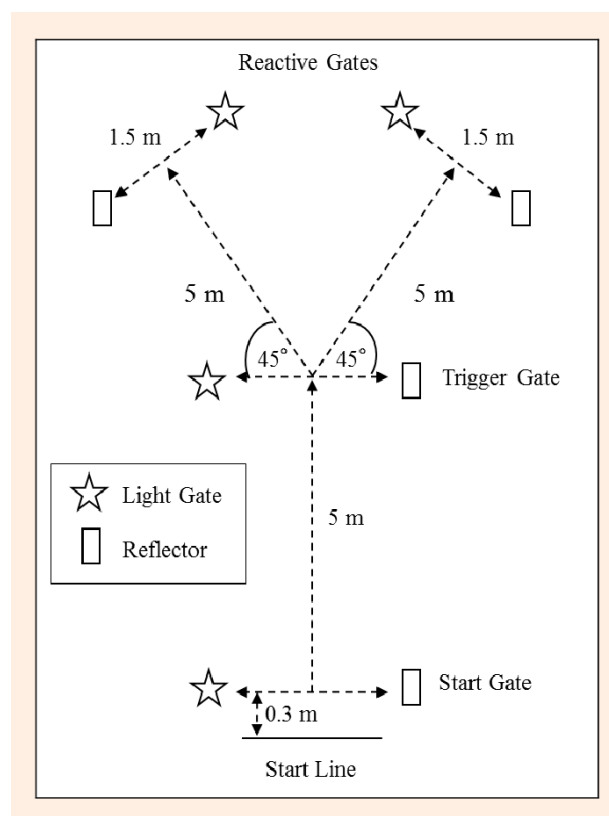


Figure 1. The Y-Shaped Agility Test.

Note. Adapted from “Effects of preventative ankle taping on planned change-of-direction and reactive agility performance and ankle muscle activity in basketballers” by Jefferiess et al., 2015, *Journal of Sports Science and Medicine*, 14 (4), p. 864.

The reactive Y-agility protocol has demonstrated high test-retest reliability ($ICC = 0.81-0.86$; $CV = 0.3-4.6\%$; Dugdale et al., 2020), and has been recognised for its construct validity in capturing the perceptual-cognitive demands that distinguish reactive agility from pre-planned movement (Sheppard et al., 2006; Zemková & Hamar, 2013). Critically, the open-skill nature of the task has been shown to differentiate athletes across competitive levels in ways that closed-skill measures cannot, demonstrating discriminatory validity in reactive decision speed and movement (Morral-Yepes et al., 2022; Pojskic et al., 2018). The addition of a stick and ball condition extended this further, ensuring the task reflected the integrated perceptual-motor demands of field hockey.

2.2.5.3 505 Change of Direction Test

The 505 Change of Direction test was used to evaluate pre-planned directional speed under both standard and sport-specific conditions. The test was set up along a 15-metre straight line with SwiftTM wireless timing gates positioned at the start line, 10-metre mark and 15-metre turning point (Figure 2). Participants sprinted from a standing start through the first gate, turned at the 15-metre line using their dominant foot, and sprinted 5 metres back through the gate. Two conditions were assessed: the first without a hockey stick, and the second while dribbling a hockey ball with a stick. Two trials were completed in each condition, with the best time used for analysis. A two-minute rest period was given between trials.

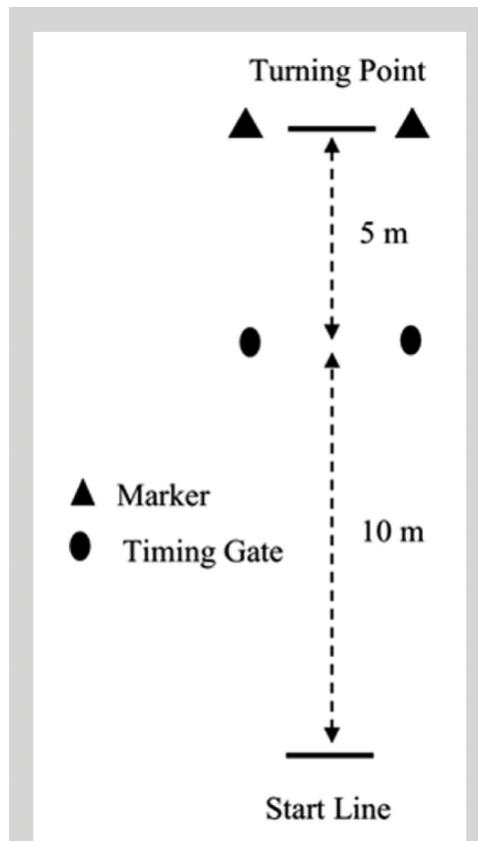


Figure 2. Structure and dimensions of the 505 Change-Of-Direction test.

Note. Adapted from “Nimphius, S., Callaghan, S. J., Spiteri, T., & Lockie, R. G. (2016). Change of Direction Deficit: A More Isolated Measure of Change of Direction Performance Than Total 505 Time. *Journal of strength and conditioning research*, 30(11), 3024–3032. <https://doi.org/10.1519/JSC.0000000000001421>”

The 505 protocol is among the most widely used and extensively validated measures of pre-planned change of direction speed in team sports, originally validated by Draper and Lancaster (1985), and subsequently shown to produce high test-retest reliability consistently across sessions ($ICC = 0.84\text{--}0.89$; $CV = 0.0\text{--}5.3\%$; Dugdale et al., 2020). The construct validity of the 505 test lies in its capacity to isolate the neuromuscular determinants of directional speed independent of perceptual-cognitive processing, making it a useful complement to the reactive agility test in distinguishing physical from cognitive contributors to agility performance (Morral-Yepes et al., 2022). A hockey dribbling condition was included to capture performance under sport-specific technical constraints.

2.2.6 Wellness Questionnaire

An adapted wellness questionnaire, based on the scale originally developed by Hooper and Mackinnon (1995), assessing sleep quality, fatigue, stress and muscle soreness, was administered before each session. The questionnaire was used to confirm that participants were in comparable physiological and psychological states across both sessions, with results reported alongside performance outcomes to allow for transparency in the interpretation of findings.

2.2.7 Statistical Analyses

All statistical analyses were conducted in Microsoft Excel. Descriptive statistics are presented as means $\pm$ standard deviations ($M \pm SD$). Paired-samples t-tests were performed to compare performance outcomes between the blue light and placebo conditions, while a two-way repeated-measures ANOVA is set to assess changes over time (pre-, mid-, and post-game) and interaction effects across time and the interaction effect between condition and time. Effect sizes were calculated using Cohen's d , with <0.2 interpreted as trivial, 0.20-0.49 small, 0.5-0.79 medium, and >0.8 large (Cohen, 1988). Statistical significance is set at $p < 0.05$, and 95% confidence intervals were reported alongside effect sizes to convey the precision of estimates. Relationships between reaction time and agility performance were assessed using Pearson r correlation coefficients with 95% confidence intervals, and interpreted based on Hopkins (2002) thresholds as trivial (0.00 – 0.09), small (0.10 – 0.29), moderate (0.30 – 0.49), large (0.50 – 0.69), very large (0.70 – 0.89), nearly perfect (0.90 – 0.99) and perfect (1.00).

2.3 Results

2.3.1 Participants

The study aimed to recruit 20 participants; however, 12 attended the testing sessions. One participant did not complete both sessions and was excluded, leaving a final sample of $n = 11$ (5 males, 6 females). Participants had a mean age of 26.5 years ($SD = 4.5$), a mean height of $M = 168.7$ cm ($SD = 9.0$), and a mean body mass of $M = 74.9$ kg ($SD = 10.6$). Participants had an average of $M = 16.7$ years of hockey playing experience ($SD = 5.1$). Participant characteristics are summarised in Table 1.

Table 1. Summary of participant characteristics

Measure	All ($n = 11$)	Males ($n = 5$)	Females ($n = 6$)
Age (years)	26.5 ± 4.5	26.4 ± 6.3	27 ± 2.8
Height (cm)	168.7 ± 9.0	175.2 ± 6.5	163.0 ± 7.1
Body mass (kg)	74.9 ± 10.6	81.6 ± 7.1	69 ± 10.1
Years Playing	16.7 ± 4.7	15 ± 4.7	18.6 ± 5.5

Note. Values are the mean $\pm$ SD

2.3.2 Wellness Questionnaire

Paired t-tests indicated no significant differences between sessions on most baseline wellness measures (Table 2), confirming that pre-session readiness could be considered equivalent across the blue light and placebo conditions.

Table 2. Adapted wellness questionnaire responses prior to testing sessions

Measure	Session 1	Session 2	<i>P</i> -value	Different
Fatigue	2.91	2.91	1.000	<i>N</i>
Sleep	4.00	3.73	.192	<i>N</i>
Muscle Soreness	3.45	3.27	.441	<i>N</i>
Stress Level	3.27	3.09	.553	<i>N</i>
Mood	4.45	3.91	.025	<i>Y</i>
Health	4.82	4.64	.341	<i>N</i>

Note. Scores are reported on a 1-5 Likert scale. *N* = no, *Y* = yes.

2.3.3 505 Change of Direction Test

A preliminary analysis confirmed that all participants performed significantly slower on the 505 test with a stick than without a stick across both conditions ($p = 3.26 \times 10^{-9}$). A two-way repeated measures ANOVA (condition x time) revealed no significant main effects of conditions, $F_{(1, 40)} = 0.36, p = .551$, no significant main effect of time, $F_{(1, 40)} = 0.78, p = .383$, and no significant condition x time interaction $F_{(1, 40)} = 0.23, p = .634$. No significant pre- to post-intervention changes were observed in either condition.

Table 3. 505 Change-of-Direction test performance at pre- and post-intervention by condition

Measure	Baseline	Post	<i>p</i> Value	Cohen's <i>d</i>	95% CI
Without Stick					
Blue Light	2.89 ± 0.24	2.88 ± 0.24	.358	-0.33	±0.72
Placebo	2.88 ± 0.20	2.78 ± 0.32	.298		
With Stick					
Blue Light	3.15 ± 0.26	3.12 ± 0.31	.457	-0.01	±0.15
Placebo	3.15 ± 0.30	3.11 ± 0.30	.305		

2.3.4 Reactive Agility Y Test

As with the 505 test, participants were slower when performing the reactive agility test with a stick compared to without a stick in both conditions ($p = 6.60 \times 10^{-13}$). A two-way repeated-measures ANOVA (condition x time) revealed no significant main effect of condition, $F(1, 40) = 0.09, p = .771$, no significant main effect of time, $F(1, 40) = 1.25, p = .270$, and no significant condition x time interaction, $F(1, 40) = 0.07, p = .790$. In the without-stick condition, the blue light intervention resulted in a significant reduction in time from baseline ($p = .027, d = 0.14 \pm 0.37$).

Table 4. Reactive agility Y-test performance at baseline and post-intervention by condition

Measure	Baseline	Post-Intervention	<i>P Value</i>	Cohen's <i>d</i>	95% <i>CI</i>
Without Stick					
Blue Light	3.04 ± 0.30	2.89 ± 0.32	.027	0.14	±0.37
Placebo	3.04 ± 0.32	2.95 ± 0.45	.169		
With Stick					
Blue Light	3.22 ± 0.40	3.23 ± 0.35	.853	0.34	±0.38
Placebo	3.48 ± 0.44	3.38 ± 0.47	.320		

2.3.5 Reaction Time

Mean reaction time data across the four time points are displayed in Figure 3. A two-way repeated-measures ANOVA revealed no significant main effect of condition, $F(1, 80) = 1.85, p = .177$; no significant main effect of time, $F(3, 80) = 1.76, p = .161$; and no significant condition x time interaction, $F(3, 80) = 0.51, p = .675$. Despite the absence of statistically significant effects, descriptive trends were observed. At half-time, the difference between conditions was associated with a *moderate* effect size ($d = 0.60, 95\% \text{ CI } \pm 0.78; p = .117$). The within-condition change was also significant in the blue light condition, with a *large* decrease

from baseline observed at halftime in the small-sided game ($p = .002$; $d = 0.91 \pm 0.47$). Response accuracy, measured as total hits, remained relatively stable across all time points in both conditions. Mean hits were comparable between the blue light (range: $M = 57$ -60) and placebo (range: $M = 56$ -61) conditions throughout the session, with no significant differences observed between conditions at any time point.

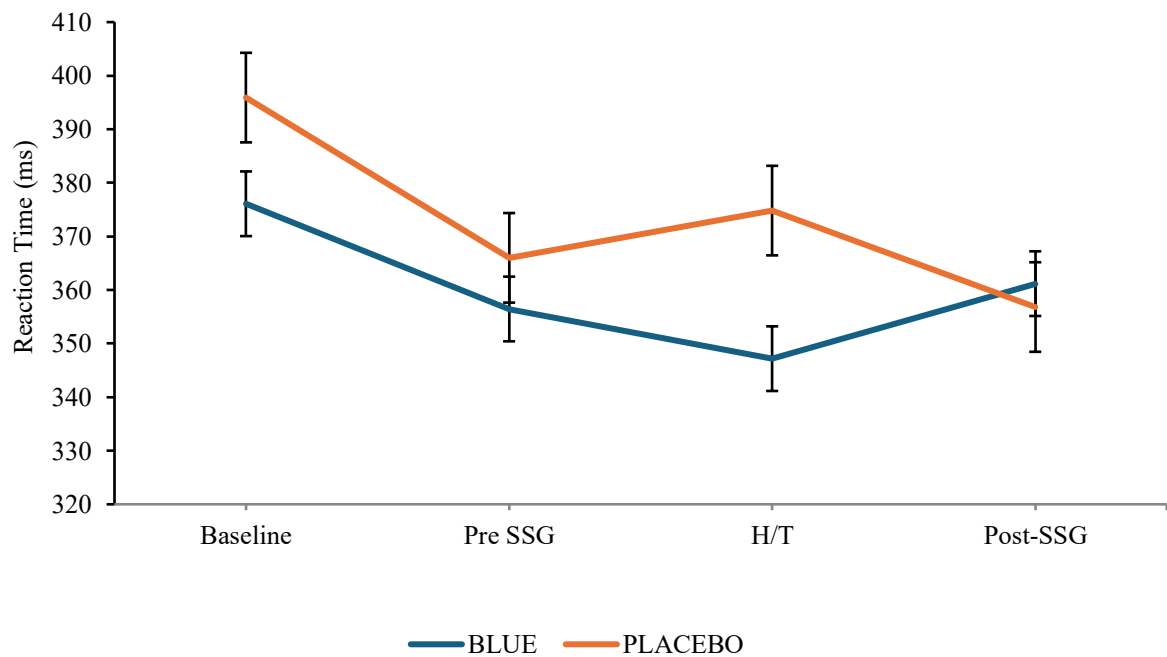


Figure 3. Mean reaction time (ms) across time points for the blue light and placebo conditions
Note. Error bars represent 95% confidence intervals.

2.3.6 Heart Rate

Mean heart rate data are displayed in Figure 4. A two-way repeated-measures ANOVA revealed a significant main effect of time, $F(3, 80) = 16.49$, $p < .001$, indicating that heart rate increased over the course of the session. There was no significant main effect of condition, $F(1, 80) = 2.34$, $p = .130$, and no significant condition x time interaction, $F(3, 80) = 0.30$, $p = .827$. Data show that heart rate increased progressively across all time points in both conditions. Between-condition comparisons at each time point were non-significant; however, at pre-SSG,

heart rate tended to be higher in the blue light condition compared to the placebo condition (128 bpm vs. 117 bpm; $p = .051$).

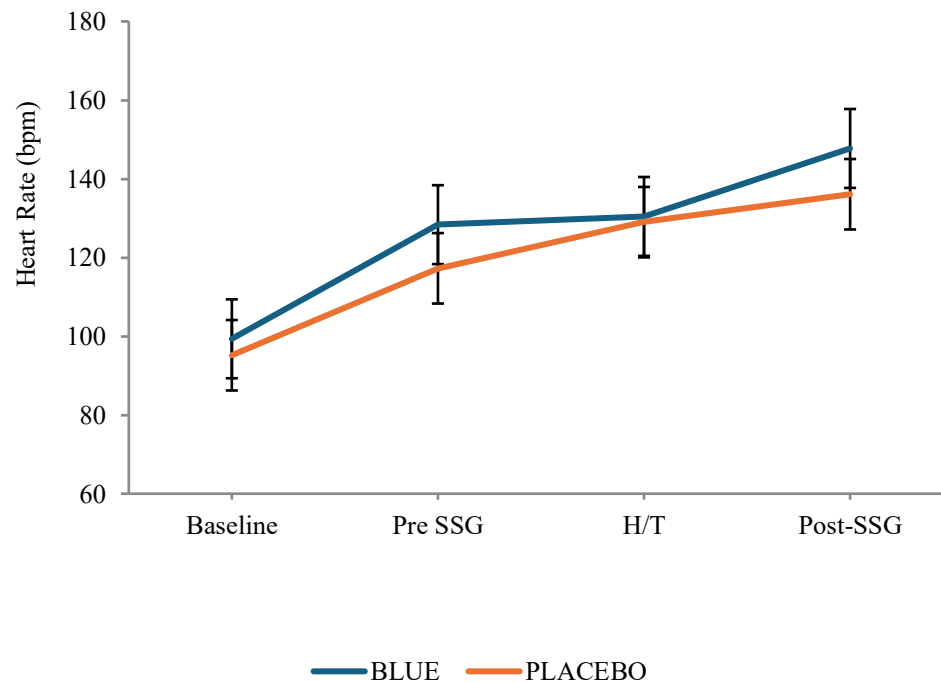


Figure 4. Mean heart rate (bpm) across session phases for the blue light and placebo conditions
Note. Error bars represent 95% confidence intervals.

2.3.7 Relationship Between Reaction Time and Agility

Pearson's Correlation analyses were conducted to examine the relationship between reaction time and agility performance across conditions. Consistent negative correlations were observed across time points and conditions, indicating an inverse relationship between reaction time and agility performance. The majority of correlations (7 out of 8) did not reach statistical significance. The only significant relationship was the *large* correlation observed between post-SSG reaction time and post-intervention agility in the without-stick condition ($r = -.62$, $p = .041$). Full correlations are presented in the table below.

Table 5. Pearson correlation between reaction time and post-intervention agility performance

Measure	Without Stick				With Stick			
	Baseline	Pre-SSG	Halftime	Post-SSG	Baseline	Pre-SSG	Halftime	Post-SSG
<i>r</i>	-.36	-.48	-.44	-.62	-.26	-.37	-.24	-.41
<i>p</i>	.276	.135	.175	.041	.440	.262	.477	.210

Note. SSG = small-sided game.

2.3.8 Exit Questionnaire

Nine of the 11 participants (82%) returned completed questionnaires. Regarding immediate perceptual effects, 33% of respondents ($n = 3$) agreed that they experienced increased alertness or concentration during the blue light session, 56% ($n = 5$) were neutral, and 11% ($n = 1$) disagreed. When asked whether blue light had a positive effect on their hockey performance, 22% ($n = 2$) agreed, 78% ($n = 7$) were neutral, and no participants disagreed. No participant reported any adverse effects such as headache or eye strain, suggesting the intervention was well tolerated. Regarding sleep, the majority of participants (78%, $n = 7$) reported no change in sleep quality following blue light exposure. One participant reported improved sleep quality, and one reported reduced sleep quality. Overall sleep quality ratings were predominantly positive, with 67% ($n = 6$) rating sleep as “Good”, 11% ($n = 1$) as “Very Good”, and 22% ($n = 2$) as “Fair”.

2.4 Discussion

Summary

This study investigated the effects of short-wavelength light exposure on reaction time and agility in competitive field hockey players, in an ecologically valid setting, using a randomised crossover design. It was hypothesised that blue light exposure would significantly improve reaction time and agility relative to a placebo condition. The findings partially support the primary hypothesis: blue light produced a significant within-condition improvement in reactive agility and a moderate between-condition reduction in reaction time at halftime in a small-sided game. However, no significant condition x time interactions were observed for any measure and change of direction speed was unaffected.

2.4.1 505 Change-of-Direction test

The confirmation that all participants were significantly slower in the with-stick condition than without demonstrates that the measurement protocol was sensitive to additional physical and technical demands, lending confidence to the validity of the assessment. Blue light exposure had no meaningful effect on 505 change of direction performance in either the with-stick or without-stick conditions, with trivial to small between-condition effect sizes. The null result does not support the study hypothesis with respect to physical agility assessed through a closed-skilled task. As the 505 test requires a pre-planned turning movement, performance is driven primarily by neuromuscular qualities such as lower limb strength, eccentric braking mechanics, and reactive strength (Bustamante-Garrido et al., 2023; Harper et al., 2024), rather than the perceptual-cognitive processes blue light is theorised to target. As established in the literature, short-wavelength light enhances performance primarily through central nervous system activation and cognitive-motor integration, rather than direct effects on

muscular function (Prayag et al., 2019; Vandewalle et al., 2018). Accordingly, the null result is consistent with prior work demonstrating that effects of blue light are specific to tasks that place meaningful cognitive demand on the performer (Beaven & Ekström, 2013; Souman et al., 2018).

2.4.2 Reactive Agility

The reactive agility Y-test produced the most meaningful finding of the study and provides the strongest directional support for the hypothesis that blue light exposure can positively influence field hockey performance. The blue light condition yielded a significant within-condition improvement of 0.15s in the without-stick condition, while the placebo condition showed a smaller, non-significant reduction of 0.09s. However, the ANOVA interaction did not reach significance, meaning the difference in the pattern of change between conditions could not be statistically confirmed.

That said, the directional pattern is consistent with both the study hypothesis and the theoretical rationale underpinning it. Reactive agility is an open-skill task requiring the rapid integration of visual stimulus perception, decision-making, and motor response initiation (Young & Ross, 2015; Zemková & Hamar, 2017), precisely the process blue light is proposed to upregulate through increased locus coeruleus and prefrontal cortex activation (Fernandez et al., 2018; Vandewalle et al., 2007). This is particularly relevant in field hockey, where perceptual speed and decision-making under pressure are recognised as defining determinants of performance (Furley & Memmert, 2012). The contrast between the null 505 result and the directionally positive reactive agility finding supports the idea that blue light selectively benefits cognitively loaded performance tasks, which aligns with Beaven and Ekström (2013). No significant changes were seen in the with-stick condition for either light condition, which

may reflect the additional coordinative demands of the implement, reducing sensitivity to any cognitive benefit, or simply the substantially wider variability in that condition.

2.4.3 Reaction Time

Despite a non-significant ANOVA, within-condition analysis provided the strongest support for the study's reaction time hypothesis. Reaction time in the blue light condition decreased progressively from baseline to half-time, representing a *moderate* within-condition effect. No corresponding improvement was observed in the placebo condition, where reaction time remained stable across all time points, suggesting that the progressive improvement observed under blue light reflected a genuine alerting response rather than a practice effect of general session warm-up. The between-condition difference at half-time was associated with a *moderate* effect size.

The progressive improvement is consistent with the established acute alerting time course of short-wavelength light (Lok et al., 2018; Souman et al., 2018). The partial regression post-SSG likely reflects exercise-induced cognitive fatigue beginning to offset the alerting benefit in the later stages of the session, which aligns with evidence that high-intensity intermittent activity can impair perceptual-cognitive processing over time (Malcolm et al., 2022). The absence of a corresponding regression in the placebo condition is likely explained by the absence of an initial alerting effect, without a sustained light-induced arousal response; reaction time had no elevated baseline from which to decline. This interpretation is supported by the convergence of both conditions at post-SSG, suggesting that exercise-induced fatigue eroded the blue light advantage rather than independently impairing placebo performance (Lok et al., 2018).

The failure of the between-condition comparison to reach significance at any time point is most likely attributable to insufficient statistical power with $n = 11$; the study was adequately

powered to detect only large effects reliably, whereas the moderate between-condition effect at half-time fell below this threshold. These findings are consistent with Chellappa et al. (2011), who reported significant improvements in sustained attention and psychomotor performance following blue-enriched light exposure, and with Beaven and Ekström (2013), who showed blue lights improved reaction speed and decision-making accuracy.

2.4.4 Heart Rate

The significant effect of time confirmed that heart rate increased systematically across the session in both conditions, validating the exercise manipulation and confirming that participants engaged appropriately with the small-sided game protocol. The absence of a significant condition, main effect or interaction indicates that blue light did not alter the overall cardiovascular response to exercise, consistent with evidence that short-wavelength light does not directly enhance aerobic capacity or muscular output (Prayag et al., 2019; Vandewalle et al., 2018).

Of note was the near-significant elevation of pre-SSG heart rate in the blue light condition relative to placebo (128 vs 117 bpm). As both conditions completed identical warm-up procedures, this difference is unlikely to reflect differential physical preparation. A more plausible explanation is that blue light elevated sympathetic arousal prior to exercise onset, consistent with evidence that ipRGC projections to the hypothalamus and brainstem autonomic centres can upregulate sympathetic tone (Fernandez et al., 2018). These data align with findings from Cajochen et al. (2005) and Chellappa et al. (2011) that blue-enriched light acutely increases heart rate and physiological activation. This elevation suggests blue light may have elevated pre-exercise arousal and readiness, which, taken alongside reaction time and agility trends, forms a coherent picture of a broader alerting effect.

2.4.5 Relationship between Reaction Time and Agility

The negative correlations observed between reaction time and reactive agility indicate that the two measures were related, although the relationship was inverse in direction. However, because lower values represent better performance for both measures, the negative correlations indicate that longer reaction times were associated with faster agility times. This finding contrasts with the expected relationship between reaction time and reactive agility, as previous literature has identified reaction time as an important component of reactive agility in invasion sports (Young & Ross, 2015; Zemková & Hamar, 2017). Therefore, the observed correlations do not provide direct support for the proposed pathway whereby enhanced processing speed would translate into improved agility. The weaker correlations in the with-stick condition likely reflect the additional technical demand of the implement, introducing variance not explained by reaction time alone.

2.4.6 Practical Implications

The findings suggest that blue light exposure before competition may offer a selective benefit to cognitively demanding aspects of performance in field hockey, specifically players' reactive agility and perceptual processing speed. These are not peripheral qualities in this sport; they are central to performance, as players must continuously read the game, anticipate opponents, and execute precise responses under time pressure (Furley & Memmert, 2012; Vaeyens et al., 2007). The intervention was well-tolerated with no participant reporting adverse effects, and the exercise protocol elicited appropriate physiological responses in both conditions, suggesting the study context was representative of competitive demands. That said, these implications are preliminary and not without limitations. For example, participants could not be blinded to their condition, which introduced the possibility of expectancy effects, since participants could tell which condition they were in. The fixed exposure dose also limits

conclusions about optimal parameters, and the absence of neurophysiological measures means the proposed cortical arousal mechanisms remain inferred rather than directly evidenced (Chellappa et al., 2011; Vandewalle et al., 2007). Additionally, the study did not meet its recruitment target, no interaction effects reached significance, and a sex-based analysis could not be conducted. Practitioners should not implement blue light protocols based on this study alone. It is also important to note that poorly timed blue light use, particularly in the evening, can suppress melatonin and disrupt sleep (Lastella et al., 2015; Prayag et al., 2019), which could be counterproductive for recovery.

2.4.7 Conclusion

Notwithstanding these limitations, results from this study suggest that acute blue light exposure before exercise may improve cognitively demanding aspects of field hockey performance, particularly reactive agility and reaction time, without meaningfully affecting change of direction speed or overall cardiovascular load. The primary hypothesis was directionally supported for both of these measures, though the absence of significant interaction effects means a firm causal claim cannot be made. These findings are consistent with Chellappa et al. (2011) and Beaven and Ekström (2013), who demonstrated cognitive and psychomotor benefits of blue light in laboratory settings, and extend those findings into a more ecologically valid, sport-specific context. Future research should recruit larger, sex-stratified samples, incorporate neurophysiological outcome measures to directly assess the arousal mechanism, and examine dose-response relationships to identify the most effective exposure parameters. If replicated with adequate statistical power, blue light exposure could represent a simple, low-cost, and non-pharmacological strategy for improving cognitive readiness and reactive performance in field hockey and similar team sport athletes.

Chapter 3: Discussion

3.1 Summary

Short-wavelength (blue) light has a well-established role in enhancing alertness and cognitive performance through non-visual neural pathways, with research consistently demonstrating that stimulation of ipRGCs activates the locus coeruleus and prefrontal cortex, regions critical for arousal, attention and decision-making (Fernandez et al., 2018; Vandewalle et al., 2007). These neurological responses underpin improvements in reaction time, sustained attention, and psychomotor performance reported across laboratory studies (Beaven & Ekström, 2013; Chellappa et al., 2011; Lok et al., 2018). Whether these cognitive benefits translate meaningfully into sport-specific performance contexts had, however, remained largely unexplored. Field hockey demands continuous, rapid decision-making, reactive agility and perceptual-motor integration under time pressure and physical fatigue (Furley & Memmert, 2012; Malcolm et al., 2022), making it a theoretically appropriate and practically relevant context in which to examine this question.

The results of the present study suggest that acute blue light exposure may produce a meaningful enhancement of cognitive readiness in competitive field hockey players, with benefits specific to tasks placing genuine perceptual-cognitive demands on the performer. Reaction time provided the most statistically robust support for this conclusion. A progressive within-condition reduction in mean reaction time was observed under blue light from baseline through to halftime, associated with a *large* effect size, while no corresponding change was observed under placebo. Critically, response accuracy remained stable across all time points, confirming that improvements in processing speed were not accompanied by a decline in response quality, a distinction of particular importance in competitive sport, where both the timing and accuracy of decisions carry direct performance consequences (Nuri et al., 2013;

Zemková & Hamar, 2017). These findings are consistent with Chellappa et al. (2011), who reported improved psychomotor vigilance and sustained attention following blue-enriched light exposure, and extend the work of Beaven and Ekström (2013), who demonstrated that blue light outperformed caffeine in improving reaction speed and decision-making accuracy by translating analogous effects into an ecologically valid, sport-specific context.

The reactive Y-agility test produced findings that further supported the primary hypothesis. A significant within-condition improvement was observed under blue light in the without-stick condition, while the placebo condition yielded only a small, non-significant change across the same period. Reactive agility is an open-skill task requiring rapid detection of an unpredictable visual stimulus, real-time decision-making, and timely motor response initiation (Young & Ross, 2015; Zemková & Hamar, 2017), precisely the perceptual-cognitive processes that blue light is proposed to accelerate through locus coeruleus and prefrontal cortex activation (Fernandez et al., 2018; Vandewalle et al., 2007). Change-of-direction performance, by contrast, was unaffected in either condition. As a closed skill, change-of-direction is a pre-planned task governed primarily by neuromuscular capacities, including lower limb eccentric strength and braking mechanics (Bustamante-Garrido et al., 2023; Harper et al., 2024). Therefore, COD performance falls outside the cognitive arousal pathway through which blue light operates (Prayag et al., 2019; Vandewalle et al., 2018). This contrast between the reactive agility and COD results is consistent with Beaven and Ekström (2013) and Souman et al. (2018), who established that the performance benefits of blue light are contingent on the cognitive demand of the tasks and provided important discriminant validity confirming that the observed effects were task-specific rather than a generalised physiological response to the intervention.

Converging support for a cortical arousal response was provided by a near-significant elevation in pre-small-sided game heart rate under blue light relative to placebo. As both

conditions completed identical warm-up procedures, this difference cannot be attributed to differential physical preparation and is more plausibly explained by blue light-mediated upregulation of sympathetic tone through ipRGC projections to the hypothalamic and brainstem autonomic centres (Fernandez et al., 2018), consistent with Cajochen et al. (2005) and Chellappa et al. (2011), who documented comparable acute heart rate elevations following blue-enriched light exposure. Across reaction time, reactive agility, and pre-exercise heart rate, the results formed a coherent and convergent pattern consistent with cortical arousal mechanisms outlined in Chapter 1, and one that is difficult to explain by placebo response alone. Taken together, the hypothesis was directionally supported across cognitively demanding measures, while the absence of any COD effect confirmed that benefits remained specific to tasks engaging the cognitive arousal pathway.

The reaction time improvement peaked at halftime before partially attenuating following the small-sided game, a temporal pattern mirroring the acute alerting window of short-wavelength light described by Lok et al. (2018) and Souman et al. (2018). The post-game regression aligned with evidence from Malcolm et al. (2022) that high-intensity intermittent field hockey activity progressively impairs cognitive processing, suggesting that exercise-induced fatigue eventually overrode the alerting benefit of blue light in the later stages of the session. This interaction between the alerting window and fatigue accumulation represents a practically important finding: it positions blue light not as a broad performance enhancer, but as a time-sensitive cognitive priming tool whose benefit is greatest when exposure is strategically timed relative to competition demands. For field hockey specifically, a sport in which perceptual-cognitive performance is most critical during the reactive, high-intensity phase of play, these findings suggest that a pre-match protocol timed to align with the peak alerting window could provide a meaningful and accessible means of optimising cognitive

readiness, with further investigation of halftime reapplication warranted given the observed vulnerability to fatigue-related attenuation in the latter stages of a session.

3.2 Practical Implications

While the findings of this study are preliminary and should be interpreted cautiously given the reduced sample size and absence of significant interaction effects, they offer directional support for the feasibility of blue light as a practical pre-performance tool in field hockey. The intervention was administered using commercially available lamps positioned within a standard changing room, a protocol that is low-cost, non-invasive, and readily transferable to club and high-performance settings without specialist equipment or medical supervision. Replication with larger, more representative samples is needed before firm recommendations can be made; however, the time course of the observed reaction time benefit offered an important practical signal. The improvement peaked in the period between exposure onset and halftime, suggesting that a pre-match protocol timed accordingly could position athletes at or near the peak of the alerting window during the early stages of competition, when reactive decision-making demands are typically high.

The data also suggested that cognitive performance was most vulnerable to exercise-induced fatigue in the latter stages of the session, raising the possibility that a brief re-exposure during the halftime interval could provide a targeted cognitive reset at the point of greatest need. For morning training sessions, contexts in which athletes frequently operate below their circadian peak performance, blue light may be particularly valuable as a countermeasure to low arousal, supporting attentional readiness and reactive processing speed before the start of a session. An important cautionary consideration, however, concerns the timing of evening use. As blue light suppresses melatonin secretion via ipRGC activation of the suprachiasmatic nucleus (Cajochen et al., 2005; Prayag et al., 2019), exposure within a few hours of intended

sleep risks disrupting circadian regulation and impairing recovery, a concern of particular relevance given that field hockey training and competition most commonly occur in the evening. Given the critical role of sleep in physical and cognitive recovery for athletes (Fullagar et al., 2015; Walsh et al., 2021), any practical implementation in evening contexts must carefully manage the interval between exposure and sleep onset. The exit questionnaire data indicated that the majority of participants reported no change in sleep quality following blue light exposure, which is an encouraging preliminary safety signal; however, subtle circadian disruption cannot be ruled out, and further controlled investigation of evening safety is warranted before widespread adoption of this intervention can be recommended.

3.3 Strengths

Several methodological features of this investigation strengthened the validity and interpretability of the findings. The randomised crossover design controlled for individual differences in baseline performance using a consistent control condition and reduced the influence of expectancy effects or demand characteristics on the observed results. The within-subject structure minimised between-participant variance, increasing sensitivity to detect true treatment effects. The stability of wellness questionnaire responses across both sessions confirmed that participants arrived in comparable physiological and psychological states on each testing day, ruling out pre-session readiness as a confounding variable. Performance for reaction time was assessed across multiple time points throughout the session rather than at a single pre- and post-exposure measurement, allowing the temporal trajectory of the blue light effect to be tracked and characterised, a feature that enabled the peak alerting window to be identified and the interaction between the alerting effect and exercise-induced fatigue to be observed. Heart rate monitoring across both conditions provided an independent physiological measure alongside the behavioural performance outcome, and the convergence of a near-

significant heart rate elevation with the reaction time and agility findings strengthened confidence that the observed pattern reflected a genuine arousal response rather than measurement noise.

The ecological validity of this study represented a further cluster of strengths. Testing was conducted on synthetic turf with a sport-specific sample of experienced, competitive field hockey players, substantially enhancing the external validity of findings relative to the non-athletic laboratory populations that have characterised the literature (Silvani et al., 2022). The inclusion of both open-skill and closed-skill outcome measures, reactive agility and change of direction speed, respectively, allowed task-specific conclusions to be drawn, providing discriminant validity that single-task designs cannot offer. Both with-stick and without-stick conditions were included for the COD and agility assessments, and the small-sided game component provided an ecologically valid fatigue stimulus that more authentically replicated the physiological and perceptual-cognitive demands of competitive play than laboratory-based exercise protocols. The timing of the session in the early evening further reflected the real-world conditions of club field hockey, strengthening the practical relevance and applicability of findings to the population for whom the intervention is most intended. Taken together, these features position the study as a methodologically robust and practically grounded contribution to an area of research that has, until now, been largely confined to non-athletic laboratory populations.

3.4 Limitations

The primary limitation of this study was sample size. The study was underpowered relative to the *a priori* target calculated to detect a moderate effect size with adequate statistical power, and this may account for why no condition-by-time interactions reached statistical significance despite several *moderate* to *large* effect sizes emerging across measures,

particularly for reaction time at halftime and reactive agility without a stick. Underpowered designs are a recognised and persistent limitation across the sports science and blue light performance literature, and the present study did not fully resolve this issue. A related consequence of the reduced sample was that it was not possible to explore whether male and female athletes responded differently to blue light exposure. Despite the established biological variation in circadian sensitivity, hormonal regulation, and light responsiveness between sexes (Hunter et al., 2023), sex-based differences remain an underexplored question in the literature, and the present sample was insufficient to examine this possibility in any meaningful way.

Several additional design constraints further limited the scope of conclusions that could be drawn. Environmental weather conditions varied between sessions, meaning that external conditions such as temperature and wind were not fully comparable across days and may have introduced performance variability on outdoor-sensitive measures. The time-consuming nature of the protocol also constrained recruitment and retention across both sessions, compounding the sample size issue. Testing at a fixed time of day introduced a further boundary on generalisability, given that the alerting effects of blue light are known to vary across the circadian cycle (Cajochen et al., 2005; Lok et al., 2018). Therefore, it is possible that different times of day, particularly early morning sessions when athletes are operating below their circadian performance peak, may yield stronger or more consistent effects than those observed here.

From a methodological standpoint, the perceptual difference between the blue light and natural light environments made double blinding impossible despite the use of an active placebo, and the possibility of expectancy effects cannot be excluded. The use of a single fixed exposure dose at one wavelength limited conclusions about optimal parameters; without dose-response data, it is not possible to determine whether different durations, intensities or wavelengths would produce stronger or more consistent performance effects. More broadly,

there remains a lack of consensus in the literature regarding the optimal timing and intensity of blue light exposure needed to enhance performance without compromising sleep or recovery, and the risks of misuse, including melatonin suppression and circadian disruption, particularly in evening training scenarios, are not yet well characterised.

Finally, the absence of neurophysiological outcome measures meant that the proposed cortical arousal mechanism, while theoretically well-grounded and consistent with the observed pattern of results, remained inferred rather than directly evidenced: inclusion of EEG, salivary cortisol, or functional near-infrared spectroscopy measures in future designs would allow the mechanism to be assessed directly and would considerably strengthen causal interpretation of the findings. Collectively, these limitations highlight the need for larger, more controlled investigations before firm conclusions can be drawn regarding the performance-enhancing potential of blue light in applied sport settings.

3.5 Ethical and Inclusive Considerations

Despite the growing interest in how short-wavelength blue light influences cognitive performance and decision-making in athletes, there is a notable absence of research that meaningfully considers cultural, ethical, or disability-related factors. Existing studies overwhelmingly focus on able-bodied, neurotypical populations, often without reporting participant demographics such as ethnicity, gender diversity, or cultural background. This lack of representation limits the applicability of findings across diverse athletic groups and raises concerns about the inclusivity of current research. In particular, there is a critical gap in studies involving athletes with disabilities or exploring how light-based intervention might be adapted for these populations. Similarly, few studies address cultural responsiveness, such as the relevance of light-based protocols within Indigenous or non-Western contexts, where cultural values and perceptions of health may differ. This narrow scope suggests a need for future

research to adopt more inclusive and responsive methodologies that align with ethical research practices and better reflect the diversity of athletic communities.

3.6 Future Research Directions

At the forefront of priorities for future research is replication with a sample size adequately powered to detect the moderate effect sizes observed. Beyond resolving the statistical limitations of the present study, a larger sample would also create the opportunity to examine whether male and female athletes respond differently to blue light exposure. Biological variation in menstrual cycle phase, hormonal fluctuations and circadian rhythm characteristics between sexes may meaningfully influence the effectiveness of blue light intervention, yet very few studies in this literature include female athletes in sufficient numbers to permit such analyses, and most existing research has recruited young, healthy male participants from Western populations. This narrow demographic scope substantially limits the generalisability of findings, given that circadian rhythm characteristics, light sensitivity, and sleep-wake patterns may vary across sexes, age groups, and ethnic backgrounds. Future research should therefore prioritise more inclusive and representative samples, incorporating female athletes, adolescents and individuals from diverse ethnic and cultural backgrounds, and should consider chronotype, habitual light exposure, and sport-specific training schedules when designing protocols, to ensure findings are applicable across the full range of athletes who might use blue light in practice.

Dose-response investigations represent a further critical direction. The present study used a single fixed protocol without examining whether different durations, intensities, or wavelengths would produce stronger or more consistent performance effects. Establishing optimal parameters for sport-specific cognitive outcomes would substantially advance the applied utility of blue light as a performance tool. Examining whether effects differ across

playing positions is also warranted, given that midfielders and strikers operating under greater volumes of open-skill decision-making may benefit disproportionately compared to defenders whose performance relies more heavily on pre-planned structures. Testing across different times of the day would further clarify whether effects are amplified in early morning sessions when athletes are operating below their circadian peak. Longitudinal designs are additionally needed to establish whether repeated light use produces cumulative benefits, habituation effects, or safety concerns across extended training blocks. Collectively, these directions point to the need for more sport-specific, ecologically valid, and inclusive research designs to fully understand the performance-enhancing potential of blue light. Such research would allow for the development of safe, targeted protocols for integrating blue light into athlete preparation and performance strategies, ensuring that its benefits can be realised responsibly and equitably across diverse athletic populations.

3.7 Conclusion

This study aimed to determine whether short-wavelength (blue) light exposure could enhance cognitively demanding aspects of field hockey performance in an ecologically valid, sport-specific setting. Across multiple independent measures, the hypothesis was directionally supported: improvements in reactive agility and reaction time, alongside a near-significant elevation in pre-exercise heart rate, formed a coherent and convergent pattern of cortical activation consistent with the proposed arousal mechanism. Notwithstanding the limitations associated with sample size, the evidence collectively supported the plausibility of blue light as a practical, non-pharmacological tool for enhancing cognitive readiness in field hockey, extending a body of evidence that has, until now, been largely confined to laboratory-based, non-athletic populations. If replicated with adequate statistical power, blue light exposure has the potential to represent a simple, low-cost, and evidence-based strategy for optimising

cognitive performance not only in field hockey, but more broadly in open-skill team sports where reactive decision-making under pressure is central to competitive success.

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Appendices

Appendix A: Ethics Approval

The University of Waikato
Private Bag 3105
Gate 1, Knighton Road
Hamilton, New Zealand

Human Research Ethics Committee
Professor Gary Wilson
Email: humanethics@waikato.ac.nz



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

10 September 2025

Emma Irwin

Division of Health

By email: ei47@students.waikato.ac.nz; emmagraceyessicairwin@gmail.com

Dear Emma,

HREC(Health)2025#58: Blue Light as a Performance Enhancer: Impacts on Decision-Making, Reaction Time and Agility in Field Hockey

Thank you for your responses to the Committee feedback.

We are now pleased to provide formal approval for your project.

Please contact the Committee by email (humanethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Regards,

A handwritten signature in blue ink, appearing to read 'G.S. Wilson'.

Professor Gary Wilson
Chairperson
University of Waikato Human Research Ethics Committee

Appendix B: Participant Information Sheet



Participant Information Sheet

Title: *Blue Light as a Performance Enhancer: Impacts on Decision-Making, Reaction Time and Agility in Field*

Hockey

Research Team: Emma Irwin (Master's Candidate), Dr Martyn Beaven (Supervisor)

Invitation

You are invited to take part in a research study conducted by Emma Irwin at the University of Waikato. This Participant Information Sheet explains why the research is being done, what it will involve and your rights as a participant. Please take the time to carefully read and understand this information, as it will help you decide if you want to take part in the study.

Please ask questions about anything that is unclear or if there is anything else you want to know more about. Participation is entirely voluntary, and you can leave the study at any time without reason. Before you decide to participate in the study, we encourage you to consult with your family, whānau, friends, or colleagues.

Background

Blue light is a type of visible light that has a short wavelength and high energy compared to other colours in the light spectrum. It is naturally present in sunlight and also commonly produced by artificial sources like LED lights, computer screens, smartphones and tablets. Blue light is known to play a role in regulating our body's internal clock (circadian rhythm), helping us feel awake and alert during the day. In recent research, exposure to blue light has been linked to improvements in alertness and certain cognitive functions. While blue light is often used in workplaces and health settings to reduce tiredness and improve focus, little is known about whether blue light can enhance performance in fast-paced, high-pressure sports like field hockey, where quick reactions, decision-making, and agility are critical. This study aims to explore whether exposure to blue light before activity can provide a short-term performance boost in hockey-specific tasks.

Purpose

To assess whether blue light exposure improves decision-making, reaction time, and agility during sport-specific tasks in field hockey players. This study aims to provide insight into whether blue light could be used as a safe, practical, and non-invasive performance aid in competitive sport.

What will we ask you to do?

To participate in the study, you will need to sign an informed consent form and complete a baseline questionnaire that collects information on your age, height, weight, and hockey history. If you agree to take part, you will complete two testing sessions at Waikato Hockey's Gallagher Hockey Centre space about one week apart. Each session will take approximately 60 to 90 minutes.

Before you begin, you will be asked a few brief questions about your health and recent activity to check on your well-being and to confirm it is safe for you to participate. All tasks will be clearly explained, and you will have the chance to practice before testing starts to establish your baseline. At the start of each session, you will be exposed to a specific type of light, either blue light or a control light, for 15 minutes while seated. The order of light exposure will be random, so you won't know which light type you are receiving in each session. After the light exposure, you will complete a series of field hockey-specific tasks on the turf. These will include activities such as completing a reaction time test, playing a small-sided game, and completing short agility drills that reflect movements typical of field hockey (e.g. directional change, sprints). The tasks are designed to assess reaction time, decision-making accuracy, and agility under conditions that are similar to those experienced in actual gameplay.

Do you have to take part?

No, participation in this study is voluntary. It is up to you to decide whether or not to participate. **Your decision to participate or not will have no impact on friendships, team selection, or club involvement.** If you do wish to

participate, you will be given the opportunity to ask the researchers any questions you have regarding the study. During the study, you can still ask any questions that occur to you, and you have the right to refuse to answer any question or do any activity. You can also withdraw your participation at any point during the study. Following the study, you will have an additional two weeks in which you can have any or all of your data withdrawn from the study. If you withdraw at any point, you will not need to provide a reason; you just have to let me (Emma Irwin) or my supervisor (Dr Martyn Beaven) know (emails below).

What are the possible risks of taking part?

The risks associated with participating in this study are low. The tasks are similar to movements performed during normal hockey training. As with any physical activity, there is a small chance of fatigue or minor muscle soreness. Blue light exposure is at safe levels, but some people may experience mild eye strain or headaches. You can stop at any time if you feel uncomfortable. These are all low risks, though, and multiple factors are in place to reduce risk.

What are the possible benefits of taking part?

You will contribute to research that may help inform new approaches to performance enhancement in sport. If you wish, you can receive feedback about your individual task performance.

Will personal or identifiable information be kept confidential?

Yes, absolutely! Your name will not appear in any reports or publications, and every effort will be made to disguise your identity. To ensure your confidentiality, all personal or identifiable data (Consent Form, etc.) will be stored securely at the University of Waikato and kept separate from any research data. All research data will be collected under a code that is specific to you so that it is automatically de-identified (i.e. will not contain your personal information). The research data collected by the research team may be used in a master's Thesis, scientific articles or presentations to help in education, coaching and sport practitioners, but this will be aggregated with other participants' data, and only the research team will have access to your results. At the end of the project, any personal information will be destroyed. Any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed, as required by the University of Waikato's research policy.

What will happen with the results?

The findings of this research will form part of a master's thesis and may be presented at academic conferences or published in journals. In addition, you will have a summary of findings sent to you when the study has been completed. This is so you can know the outcomes of the study.

Who's responsible?

If you have any questions or concerns about the project, either now or in the future, please feel free to contact:

Emma Irwin

Master's Student – Human Performance Science

emmagraceyessicaairwin@gmail.com / ei47@students.waikato.ac.nz

Dr Martyn Beaven

Senior Lecturer – Exercise Physiology and Endocrinology

martyn.beaven@waikato.ac.nz

This research project has been approved by the Human Research Ethics Committee of the University of Waikato under HREC(HEALTH)2025#58. For any ethical questions or concerns, please contact the Chair of the Committee, email human-ethics@waikato.ac.nz, postal address, University of Waikato, Te Whare Wānanga o Waikato, Private Bag 3105, Hamilton 3240.

Appendix C: Participant Consent Form



Participant Consent Form

Title: *Blue Light as a Performance Enhancer: Impacts on Decision-Making, Reaction Time and Agility in Field Hockey*

Research Team: Emma Irwin (Master's Candidate), Dr Martyn Beaven (Supervisor)

*I have read the **Participant Information Sheet** for this study and have had the details explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.*

I also understand that:

- *I am free to withdraw from the study at any time or to decline to answer any particular questions.*
- *I can withdraw any information I have provided up to two weeks after participating in the research activities by contacting the principal investigator.*
- *My decision to participate will have no impact on friendships, team selection, or club involvement.*
- *Any data or answers will remain confidential regarding my identity through a coding system.*
- *The data might be published, so every effort will be made to ensure confidentiality and anonymity. However, anonymity cannot be guaranteed.*

I agree to provide information to the researchers under the conditions of confidentiality set out on the Participant Information Sheet.

Consent to Participate

I agree to participate in this study under the conditions set out in the Participant Information Sheet.

Participant

Signature: _____

Name: _____

Date: ____ / ____ / ____

Researcher

Signature: _____

Name: _____

Date: ____ / ____ / ____

Appendix D: Baseline Questionnaire



Baseline Questionnaire

Blue Light as a Performance Enhancer: Impacts on Decision-Making, Reaction Time and Agility in Field Hockey

Name: _____

Date of Birth: _____

Sex: _____

Height: _____

Weight: _____

Years Playing Hockey: _____

Position: _____

Appendix E: Athlete Wellness Questionnaire



Athlete Wellness Questionnaire

Blue Light as a Performance Enhancer: Impacts on Decision-Making, Reaction Time and Agility in Field

Hockey

This questionnaire is designed to assess your perceived well-being before the start of the session. It asks about fatigue, sleep quality, general muscle soreness, etc, using a five-point scale. Please read each row carefully and circle the answer that best describes how you feel right now. The scale runs from 1 (e.g. very tired/sore) through to 5 (e.g. very fresh/feeling great). There are no right or wrong answers; simply respond honestly based on how you feel at this moment. The questionnaire should be completed upon arrival, before any testing begins. If you have any questions while filling it out, please ask the researcher.

	1	2	3	4	5
Fatigue	Always tired	More tired than normal	Normal	Fresh	Very Fresh
Sleep Quality	Insomnia	Restless Sleep	Difficulty Falling Asleep	Good	Very Restful
General Muscle Soreness	Very Sore	Increase in Soreness/Tightness	Normal	Feeling Good	Feeling Great
Stress Levels	Highly Stressed	Feeling Stressed	Normal	Relaxed	Very Relaxed
Mood	Highly Annoyed/irritable/down	Snappiness at teammates, family and co-workers	Less interested in others &/or activities than usual	A generally good mood	A very Positive mood
Health	Very sick		Slight symptoms or illness		Optimal Health

Adapted from: Hooper, S., & Mackinnon, L. (1995). Monitoring overtraining in athletes. *Sports Medicine*, 20(5), 321-327. <https://doi.org/10.2165/00007256-199520050-00003>.

Appendix F: Exit Questionnaire



Exit Questionnaire

Title: *Blue Light as a Performance Enhancer: Impacts on Decision-Making, Reaction Time and Agility in Field*

Hockey

Thank you for taking part in this study. Please take a few minutes to reflect on your experience and provide your feedback. Your responses are anonymous and will help us understand how the light intervention may have influenced your performance and well-being.

Name: _____

1. During the blue light sessions, did you feel any immediate effect (e.g., increased alertness, focus)?
☐ Not at all
☐ A little
☐ Moderately
☐ Very much
2. Did you feel that exposure to the blue light had a positive effect on your hockey performance?
☐ No effect
☐ Slight positive effect
☐ Moderate positive effect
☐ Strong positive effect
3. Did you notice any negative effects from the blue light exposure (e.g., headaches, eye strain)?
☐ None
☐ Mild
☐ Moderate
☐ Severe

If yes... what were they? _____
4. Did you feel the blue light exposure affected your sleep quality?
☐ No effect
☐ Slightly disrupted sleep
☐ Moderately disrupted sleep
☐ Strongly disrupted sleep
5. On nights after blue light exposure, how would you rate your sleep overall?
☐ Very poor
☐ Poor
☐ Fair
☐ Good
☐ Very good
6. Any additional comments about your experience with the blue light intervention?