DOCTORAL THESIS [Ph.D.]

COGNITIVE AND EMOTIONAL FUNCTIONING RELATED TO CLIMBING PERFORMANCE

C-HIPPER Project
Climbing High Performance International Project

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C-HIPPER Project
Climbing High Performance International Project

Ph.D. Thesis

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FUNCIONAMIENTO COGNITIVO Y EMOCIONAL RELACIONADO CON EL RENDIMIENTO EN ESCALADA

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PhD

Miembros del Tribunal

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FUNDINGS AND GRANTS

The present Ph.D. Thesis has been made possible thanks to significant research and experiences gained during my doctoral studies. Foremost, this work is based on the insights and findings of the C-HIPPER Project, which laid the foundational concepts addressed in this dissertation. Additionally, my involvement in the SONRÍE, though not directly related to the Ph.D. Thesis, has provided me with experience and has been instrumental in shaping my academic and professional growth during this period.

1. Research Project: "Aspectos Fisiológicos y Psicológicos en Escalada: Proyecto C-HIPPER"

   Reference: PR2016-056

   Date: 01/01/2017 to 01/01/2018

   Funding: 1800€

   Principal investigator: Vanesa España Romero. University of Cadiz

2. Research Project: "Actividades físicas en el medio natural en personas con depresión. Efectos sobre el bienestar psíquico y social. Estudio SONRÍE"
   Reference: PI-0068-2018.

   Date: 01/12/2018 to 31/12/2020

   Funding: 60.174€

   Principal investigator: Vanesa España Romero. University of Cadiz

LIST OF SCIENTIFIC PUBLICATIONS

The present Ph.D. Thesis manuscript is comprised of four scientific publications and the development of an invention listed below:

I. Attentional differences as a function of rock climbing performance. Garrido-Palomino, I; Fryer, S; Giles, D.; González-Rosa, J.J.; España-Romero, V. (2020). Frontiers in Psychology. https://doi.org/10.3389/fpsyg.2020.01550. Impact Factor JCR 2020: 2.988. Psychology, Multidisciplinary. Position:43/140. Quartile: 2

II. Cognitive function of climbers: An exploratory study of working memory, brain hemodynamic responses and climbing performance. Garrido-Palomino, I; Giles, D.; Fryer, S; González-Montesinos, J.L.; España-Romero, V. (2024). Spanish Journal of Psychology. Impact Factor JCR 2022: 2.3. Psychology, Multidisciplinary. Position: 75/147. Quartile: 3**. In press**

III. Sistema autónomo y portable para el entrenamiento de la memoria de trabajo y la técnica en escalada. Garrido-Palomino, I. & España-Romero, Vanesa (2023). U202231081. Oficina Española de Patentes y Marcas (OEPM). Volume II: Inventions. Nº. 6512, of the Boletín Oficial de la Propiedad Industrial, dated October 10, 2023

IV. Role of emotional intelligence on rock climbing performance. Garrido-Palomino, I., & España-Romero, V. (2019). *RICYDE: Revista Internacional de Ciencias Del Deporte*, *15*(57), 284–294. https://doi.org/10.5232/ricyde2019.05706. Impact Factor JCR 2019: 0.35. Sport Sciences. Position: 88/116. Quartile: 4

V. Fear of falling in women: A Psychological training intervention improves climbing performance. Garrido-Palomino, I., & España-Romero, V. (2023). Journal of Sports Sciences. 41(16), 1518-1529. https://doi.org/10.1080/02640414.2023.2281157. Impact Factor JCR 2022: 3.4. Sport Sciences. Position: 20/87. Quartile: 1

LIST OF SCIENTIFIC POSTER AND COMUNICATIONS

The results obtained during the completion of the Ph.D. Thesis have been presented through oral presentations and posters at the following national and international scientific congresses:

1. Poster. "A Comparison of Emotional Intelligence in Elite and Expert rock climbers". Editorial Information of the Proceedings: International symposium. Active brain for all: Exercise, cognition and mental health. Granada, España. June 12, 2017. ISBN: 978-84-697- 3918-1.
2. Communication. "Is Vigilance related to Rock Climbing Performance?". Editorial Information of the Proceedings: IV International Rock Climbing Research Congress. Chamonix, Francia. July 9-15, 2018.
3. Poster. "Relationship between healthy outdoor physical activity and attention". VI Simposio EXERNET. Investigación en ejercicio, salud y bienestar. "Exercise is Medicine". Pamplona, October 19-20, 2018.
4. Communication. "Working Memory Functioning in Outdoor Climbers". 5th International Rock Climbing Research Congress. Tokyo, June 11-14, 2021.
5. Communication. "A Case Study: Psychological Intervention Improves Climbing Performance". 5th International Rock Climbing Research Congress. Tokyo, June 11-14, 2021.
6. Communication. "Impacto de las emociones sobre el rendimiento en deportes individuales". I Congreso Virtual de Psicología del Deporte. Consejo Nacional del Deporte de la Educación. México, November 23, 2021.
7. Communication. "Psychological changes with the repeated practice of a specific route". 6th International Rock Climbing Research Congress. Bern (Switzerland), August 7 –10, 2023.

SOCIAL MEDIA PRESENCE

The results of the Ph.D. Thesis have been made accessible to the general public through various scientific outreach activities through social networks.

1. Website development. **Be CHIPPER**.
2. Instagram account. **@chipper_climber.** With 585 "Followers" and 38 publications**.** As of March 29, 2024.
3. Instagram. **Proyecto C-HIPPER** (@inmagarrido_psicóloga). With 699 "Views" and 37 "Likes" (November 17, 2021). As of March 29, 2024.
4. **Twitter contest Hilo-Tesis.** Fundación Ignacio Larramendi (@filarramendi). Ref. AD2023-020. With 10 Retweets, 34 "Likes" y 5586 "View" (May 7, 2023). As of March 29, 2024.
5. Instagram. **Miedo a caer en escalada** (@inmagarrido_psicóloga). With 689 "Likes" and 152 "Save". (November 25, 2023). As of March 29, 2024.

ABREVIATIONS

AC: Accuracy of response

ANOVA: Analysis of variance

ANCOVA: Analysis of covariance

b: Unstandardized Regression Coefficient

BMI: Body Mass Index

CI: Confidence Intervals

cm: centimeters

CG: control group

C-HIPPER: High-Performance International Rock-Climbing Research

CRF: Cardiorespiratory Fitness

CSAI-2 R: Revised Competitive State Anxiety Inventory-2

d: delta de Cohen

DT: Detection Task

eCorsi: electronic Corsi-block task

EI: Emotional Intelligence

ES: effect size

F: variance ratio

f: effect size

FP1: frontal pole of the left hemisphere.

FP2: frontal pole of the right hemisphere.

HHb: deoxygenated hemoglobin

IA: Interoceptive awareness

IFSC: International Federation of Sport Climbing

IRCRA: International Rock Climbing Research Association

LL: lower confidence interval

M: mean

m^2: Square meter

MAIA: Multidimensional Assessment of Interoceptive Awareness

MD: mean differences

min: minutes

mm: millimeters

mol/L: micromoles per lite

ms: milliseconds

MSCEIT: Mayer-Salovey-Caruso Emotional Intelligence Test

NIRS: Near Infrared Spectroscopy

Kg: kilogram

O_2Hb: oxygenated hemoglobin

p: P-value

PELB: The Psychology Experiment Building Language

PFC: prefrontal cortex

PG: Psychological Group

r: Pearson correlation

$\mathbf{R^2}$: coefficient of determination

$\mathbf{R^2}$ **adj**: adjusted coefficient of determination

Rho: spearman correlation

RT: Reaction Time

s: second

SD: Standard Deviation

SSEIT: Schutte Self Report Emotional Intelligence Test

STATA: Statistical software for data science

t: t-statistic

TG: training Group

tHb: total hemoglobin

TOI: tissue oxygenation index

$\mathbf{VO_2}$ **max**: Maximum oxygen consumption

UL: upper confidence interval

WM: working memory

yrs.: years

β: Standardized Regression Coefficient

η^2: eta squared

η_p^2: partial eta squared

$\triangle$: Delta

µM: micromolar

χ^2: Kruskal-Wallis coefficient

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ABSTRACT

ABSTRACT

The recent inclusion of climbing in the 2020 Olympic Games has sparked a growing scientific interest in the sport in recent years, particularly concerning determinants of sports performance. While numerous studies underscore the influence and significance of psychological aspects on climbing performance, there remains a pressing need for further research in this area. To address this knowledge gap, the general aim of the present Ph.D. Thesis was to enhance understanding of psychological parameters within cognitive, emotional, and brain activity domains among climbers of different levels, from recreational to elite, specifically examining how these factors interrelate and contribute to climbing performance.

Within the framework of the C-HIPPER project ("Climbing High Performance International Project") four studies were conducted, along with an invention, involving 136 climbers (60 women), with levels ranging from 5+ to 8b+ on the French scale. **Study I**, examined the attentional capacity in 35 (10 women) climbers, employing the Determination Task and the Signal Detection Task. **Study II**, evaluated the working memory capacity in 28 (5 women) climbers, using the eCorsi task, and the hemodynamic responses of the prefrontal cortex recorded via Near-Infrared Spectroscopy (NIRS). An **Invention**, now patented, introduced a system for training working memory and climbing technique. **Study III** assessed emotional intelligence in 42 (14 women) climbers, using the Schutte Self Report Emotional Intelligence Test (SSEIT) and the Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT). Lastly, **Study IV** implemented a psychological intervention addressing emotional regulation in 11 women with fear of falling, evaluating anxiety and interoceptive awareness through the Competitive State

Anxiety Inventory-2 (CSAI-2 R) and the Multidimensional Assessment of Interoceptive Awareness (MAIA) questionnaire, respectively, across Training and Control groups.

The main results derived from these studies suggest that i) greater attentional control in high-level climbers compared to lower-level climbers (Study I); ii) an inverse relationship between WM capacity and climbing level, with age, gender, educational level, and climbing experience as significant predictors (Study II); iii) variation in prefrontal cortex hemodynamic reflecting differences in WM capacity between expert and elite climbers (Study II); iv) significant differences in prefrontal cortex hemodynamics between men and women present, despite similar WM capacity (Study II); v) the development of a novel system for WM and technique training in climbing (Invention); vi) differences in emotional intelligence as an ability, specifically in a person's ability to use emotions effectively to facilitate cognitive thinking, among climbers of different levels (Study III); vii) no significant differences in trait emotional intelligence between climbers of different levels (Study III); viii) significant differences in trait emotional intelligence between men and women (Study III); ix) a psychological intervention induced improvements in lead climbing level and interoceptive awareness, and reduced anxiety in women with fear of falling (Study IV).

In general, the findings of this Ph.D. Thesis indicate that differences among climbers of different levels in cognitive functions, such as attention and WM, as well as in the emotional domain, in EI and emotional regulation, may play a crucial role in climbing performance.

RESUMEN

La reciente inclusión de la escalada en los Juegos Olímpicos de 2020 ha generado un creciente interés científico en el deporte en los últimos años, especialmente en lo que respecta a los determinantes del rendimiento deportivo. Si bien numerosos estudios destacan la influencia y la importancia de los aspectos psicológicos en el rendimiento en escalada, todavía existe una necesidad apremiante de más investigación en esta área. Para abordar esta brecha de conocimiento, el objetivo general de la presente tesis doctoral fue aumentar el conocimiento sobre diversos dominios cognitivos, emocionales y de actividad cerebral entre escaladores de diferentes niveles, desde recreativos hasta élite.

Dentro del marco del proyecto C-HIPPER ("Climbing High Performance International Project"), se llevaron a cabo cuatro estudios, así como una invención, que involucraron a 136 escaladores (60 mujeres), con niveles que van desde 5+ hasta 8b+ en la escala francesa. El **Estudio I** examinó la capacidad de atención en 35 escaladores (10 mujeres) utilizando la Tarea de Determinación y la Tarea de Detección de Señales. El **Estudio II** evaluó la capacidad de memoria de trabajo en 28 escaladores (5 mujeres) utilizando la tarea de eCorsi, y se registraron las respuestas hemodinámicas de la corteza prefrontal mediante espectroscopía de infrarrojo cercano (NIRS). El **Estudio III** evaluó la inteligencia emocional en 42 escaladores (14 mujeres) utilizando el Test de Inteligencia Emocional de Schutte (SSEIT) y el Test de Inteligencia Emocional de Mayer-Salovey-Caruso (MSCEIT). Una **Invención**, ahora patentada, introdujo un sistema para entrenar la memoria de trabajo y la técnica de escalada. Por último, el **Estudio IV** implementó una intervención psicológica dirigida a la regulación emocional en 11 mujeres con miedo a caer, evaluando la ansiedad y la conciencia interoceptiva a través del Inventario de Ansiedad Competitiva-2 (CSAI-2 R) y el cuestionario de Evaluación Multidimensional

de Conciencia Interoceptiva (MAIA), respectivamente, en grupos de Entrenamiento y Control.

Los principales resultados derivados de estos estudios sugieren que: i) hay un mayor control atencional en escaladores de alto nivel en comparación con escaladores de nivel inferior (Estudio I); ii) existe una relación inversa entre la capacidad de memoria de trabajo y el nivel de escalada, siendo la edad, el género, el nivel educativo y la experiencia en escalada predictores significativos (Estudio II); iii) hay variación en la hemodinámica de la corteza prefrontal que refleja diferencias en la capacidad de memoria de trabajo entre escaladores expertos y élite (Estudio II); iv) existen diferencias significativas en la hemodinámica de la corteza prefrontal entre hombres y mujeres presentes, a pesar de una capacidad de memoria de trabajo similar (Estudio II); v) existen diferencias en la inteligencia emocional como habilidad, específicamente en la capacidad de una persona para utilizar las emociones de manera efectiva para facilitar el pensamiento cognitivo, entre escaladores de diferentes niveles (Estudio III); vi) no hay diferencias significativas en la inteligencia emocional como rasgo entre escaladores de diferentes niveles (Estudio III); vii) existen diferencias significativas en la inteligencia emocional como rasgo entre hombres y mujeres (Estudio III); viii) se desarrolló un nuevo sistema para el entrenamiento de la memoria de trabajo y la técnica de escalada (Invención); ix) una intervención psicológica provocó mejoras en el nivel de escalada en liderazgo y en la conciencia interoceptiva, así como una reducción de la ansiedad en mujeres con miedo a caer (Estudio IV).

En general los hallazgos de la presente Tesis Doctoral indican que diferencias entre escaladores de distinto nivel en funciones cognitivas, como la atención y la memoria de trabajo, así como en el dominio emocional, en inteligencia emocional y regulación emocional, pueden desempeñar un papel crucial en el rendimiento en la escalada.

THEMATIC JUSTIFICATION OF THE THESIS

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In recent years, climbing has experienced a notable increase in popularity, both among enthusiasts and elite athletes. This surge in climbing practice has stimulated renewed interest in the scientific community, which seeks to understand the various physiological and psychological aspects involved in this complex sport. Specialized literature published in recent years indicates that climbing is a sport that presents high emotional demands, particularly induced by high levels of anxiety (Baláš et al., 2017; Hodgson et al., 2009). Moreover, it has been demonstrated that climbing requires a significant demand for attention (Nieuwenhuys et al., 2008), influenced by the difficulty of the route (Bourdin et al., 1998), and that WM is a cognitive function implicated in the process (Green & Helton, 2011), which in some way relates to attention. Given the complexity of both the human brain and human behavior, along with the uniqueness of climbing, the study of cognitive and emotional processes in this sport presents itself as a challenging task.

The present Ph.D. Thesis is part of the "C-HIPPER Project" (Physiological and Psychological Aspects in Climbing), directed by Dr. Vanesa España Romero since 2015 and funded lastly by the University of Cádiz (PR2016-056). This initiative aims, in terms of psychological aspects, to address the existing gap in scientific literature regarding the cognitive and emotional variables that may influence climbing performance. Our analyses and discussions are designed to highlight these considerations, with the goal of mitigating potential biases and contributing to a more comprehensive understanding of the cognitive and emotional processes in climbing performance.

The results obtained in this project, within which the present Ph.D. Thesis is framed, aim to contribute to a deeper understanding of the cognitive and emotional differences associated with climbing performance. In addition to identifying these disparities, they provide key information to understand the cognitive processes of athletes in this field. Given the limited scientific evidence related to these aspects, the results obtained lay the groundwork for future research in the field. These findings can also serve as a guide for the design of training plans aimed at improving these skills and, consequently, climbing performance.

CRITICAL ANALYSIS OF THE BACKGROUND

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Sport climbing

The proliferation of urban climbing facilities has long driven an increase in climbing participants and fostered scientific investigation into both physiological and psychological aspects of the sport—a trend well-documented since the early 2000s (España-Romero et al., 2006; España-Romero, Ortega Porcel, et al., 2009; Sanchez et al., 2019; Watts et al., 2003). Nonetheless, the inclusion of climbing as an Olympic sport in the 2020 Tokyo Games constituted a milestone that marked significant global recognition of the sport. This resurgence has not only sustained the growth in participant numbers but also expanded the scope of scientific inquiry into climbing, now encompassing a wider range of physiological and psychological aspects. This evolving landscape reflects climbing's increasing recognition as a multifaceted sport, stimulating continued research into its complexities and the factors influencing performance.

Sport climbing is a complex sport composed of different disciplines encompassing bouldering, lead climbing, and speed climbing (Draper et al., 2008). The practice of each discipline involves ascending routes designed on natural or artificial climbing walls without falling. Each discipline of climbing, whether bouldering, lead climbing, or speed climbing, includes various modalities distinguished by the level of route knowledge (on-sight or red-point), as well as the different physiological and psychological factors that influence climbers (Draper et al., 2008; Limonta et al., 2020). Specifically, on-sight climbing refers to ascending a route without any prior knowledge and on the first attempt, whereas rehearsed climbing involves ascending a route as many times as necessary until completed without falls (Giles et al., 2014). Another distinctive feature of climbing is the climbing style, which describes the safety protocol protecting the climber in case of a fall. Safety protocols in bouldering, which are routes of shorter height, are commonly protected by crash pads (Giles et al., 2014). Lead climbing, characterized by longer ascents, can be protected with a "top-rope" where any risk of fall is avoided (Giles et al., 2014). Alternatively, climbers can lead the climb without the protection of the rope above, where there is a risk of fall depending on the distance the person has climbed since the last protection point (Giles et al., 2014). Both climbing style (lead climbing vs. top-rope climbing) (Draper et al., 2010; Fryer et al., 2012) and modality (on-sight vs. red-point) (Limonta et al., 2020) have been shown to have a significant influence on the climber's psychology during climbing, modulating anxiety levels, which affects emotional experience and performance on the wall. Thus, lead climbing style and on-sight modality are widely recognized to be mostly influenced by psychological aspects, such as anxiety (Draper et al., 2010; Limonta et al., 2020) due to the risk of fall and lack of prior route information, respectively. Therefore, the nature and complexity of climbing require athletes to possess good physical abilities, such as strength, endurance, agility, and balance, along with mental control to respond to the technical difficulty of movements (España-Romero et al., 2006; España-Romero, Ortega Porcel, et al., 2009; Giles et al., 2006; Hodgson et al., 2009; Morrison & Schöffl, 2007). Hence, the skill level of climbers is established based on this physical and psychological demand required to complete the route. Specifically, athletes' performance is evaluated in terms of their ability to complete a specific route without falls in the shortest time possible or to reach the farthest point on a route representing a certain level of difficulty (grade). In this sense, self-reported grade provides a valid and accurate reflection of climbing performance (Draper et al., 2011, 2016).

Overall, the majority of research efforts in climbing have focused on analyzing physiological parameters (Espana-Romero et al., 2012; España-Romero, Artero, et al., 2009; Fryer et al., 2016, 2017, 2018; Giles et al., 2016; Watts, 2004; Watts & Drobish, 1998; Zarattini et al., 2018), body composition factors (España-Romero et al., 2006; España Romero et al., 2009; Giles et al., 2021; Téllez et al., 2019; Watts et al., 1993), biomechanics (Cha et al., 2015; Seifert et al., 2014) and perceptual aspects (Hacques et al., 2021, 2022; Marcen-Cinca et al., 2022) all of which are considered determinants of performance on this sport. However, despite the widespread consensus on the importance of the psychological component in climbing, research in this area remains relatively limited (Giles et al., 2006; Saul et al., 2019; Sheel, 2004; Watts, 2004).

Psychological perspective in sport climbing

From a psychological perspective in climbing, two fundamental lines of research are particularly notable. The first line of research delves into the *cognitive domain*, focusing on how cognitive functions like attention (Bourdin et al., 1998) and memory (Boschker et al., 2002; Green & Helton, 2011; Epling et al., 2018), as well as the mental processes involved in movement planning (Sanchez et al., 2019; Stanković et al., 2011) and memory differences among climbers (Heilmann, 2021; Whitaker et al., 2019), contribute to problem-solving and optimizing performance on the wall.

The second line focuses on the *emotional domain*, examining how anxiety influences climbers' performance and experience. Studies in this area (Dickson et al., 2012; Draper et al., 2008, 2010; Fryer et al., 2012; Hardy & Hutchinson, 2007; Hodgson et al., 2009; Limonta et al., 2020; Nieuwenhuys et al., 2008; Pijpers et al., 2005, 2006) had provided valuable insights into how anxiety affects overall performance, including before (Aşçi et al., 2007) and during climbing (Sanchez et al., 2010) in competitive context. However, despite these efforts, the emotional or cognitive characteristics that differentiate the most successful climbers have received relatively little attention in the scientific literature.

Cognitive domain in climbing

A significant challenge in the scientific community has been to determine whether athletes exhibit distinct key cognitive functions crucial for success in sports (Voss et al., 2010). Among these, executive functions stand out, encompassing complex cognitive control processes necessary for organizing tasks, assessing risks, making decisions, managing emotions, and adapting to unexpected events. This set includes core functions such as attention or WM (Banich, 2009; Diamond, 2013). Attention is considered a pivotal cognitive processes that involves filtering and selecting behaviorally relevant information from the environment for further analysis or action (Le Pelley et al., 2016). Conversely, WM is a multicomponent system responsible for the active retention of pertinent information over short periods, thus enabling complex cognitive activities (Cowan, 2010). There is a consensus that attention and WM are closely related, contributing significantly to cognitive efficiency. Notably, both functions share a brain network with neural underpinning located in the PFC, supported by extensive research (Bahmani et al., 2019; Chai et al., 2018; Fishburn et al., 2014; Kardan et al., 2022; Xu et al., 2014). In this context, theories and models suggest that attention plays a crucial role in the functioning of WM (Baddeley, 1992; Cowan et al., 2010). One of the prevailing theories suggests that the efficacy of WM depends on attentional control and its interaction with information from both short- and long-term memory. This interaction serves as a framework for selecting and transferring data into WM, with attentional control being vital for maintaining and manipulating this information, thereby supporting ongoing cognitive tasks (embedded-processes model of Cowan et al., (2010)).

In sports sciences, cognitive functions in athletes have been studied mainly from two different theoretical frameworks, based on the use of different methodological approaches (Voss et al., 2010; Williams & Ericsson, 2005).

Theoretical model focused on the cognitive component skills approach

The cognitive component skills approach focuses on evaluating whether sports expertise correlate with superior fundamental cognitive performance, typically assessed in laboratory settings (Voss et al., 2010). Overall, this approach is founded on the belief that training and involvement in sports can enhance broad cognitive capacities, including attention, WM, inhibitory control, and cognitive flexibility. Instead of solely concentrating on athletic performance, this methodology is rooted in the concept that engagement in sports can yield positive outcomes for cognitive advancement transferable to other areas of everyday life. Research under this methodology has examined athletes' performance in key executive functions such as attention and WM, through basic cognitive tests.

Attention

In support of the cognitive component skills approach, a quantitative meta-analysis conducted by Voss et al. (2010) revealed that athletes exhibited enhanced performance in processing speed measures and various attentional paradigms. Superior performance of elite athletes compared to less elite athletes in attention tasks has been evidenced in sports such as martial arts (Sanchez-Lopez et al., 2016), basketball (Qiu et al., 2018), soccer (Heppe et al., 2016), volleyball (Kioumourtzoglou et al., 1998), hockey (Laborde et al., 2016; Marczak & Ginszt, 2017), table tennis (Kajbafnezhad et al., 2011), or winter sports (skiing, duathlon, alpine skiing) (Jordalen et al., 2018).

Specifically in climbing, evidence suggests that this sport requires attentional control (Bourdin, C; Teasdale, N; Nougier, 1998; Green & Helton, 2011; Young, 2011). One of the experimental approaches used to study attention associated to motor performance is the locomotor-cognitive dual-task paradigm (Leone et al., 2017). In this paradigm, participants are asked to perform two tasks involving cognitive effort simultaneously (e.g., motor control climbing and remembering a list of words), which requires them to use their attentional resources and other cognitive processes. This approach helps to understand how tasks compete for limited cognitive resources such as attention and WM (Hocking et al., 2020; Logan & Gordon, 2001). Through this paradigm, Bourdin et al. (1998) found that attentional demands increase with the difficulty of a climbing task, further affecting climbing efficiency. Similarly, Young, (2011) demonstrated that climbers who were distracted by a task requiring heightened attention performed significantly worse, as indicated by increased climbing time, compared to non-distracted climbers while ascending. Green & Helton, (2011) also showed that attentional interference negatively impacted climbing performance. They found that climber's efficiency and distance ascended decreased when their attention was diverted to unrelated tasks, such as memory task.

The cognitive advantage associated to sport expertise has been also attributed to greater CRF by a portion of scientific literature (Ballester et al., 2017; Ciria et al., 2017; Luque-Casado et al., 2016; Sanabria et al., 2019). These positive effects of CRF on cognitive function in general have been linked to an increased capacity of the heart to deliver oxygenated blood to cerebral structures (Colcombe & Kramer, 2003), enhanced cerebral blood flow (Brown et al., 2010), and elevated levels of brain-derived neurotrophic factor (Vaynman et al., 2003). Consequently, given that rock climbing ability has previously been linked with high CRF (Aras & Ewert, 2016), and considering the known relationship between CRF and attention (Ballester et al., 2017; Ciria et al., 2017; Luque-Casado et al., 2016; Sanabria et al., 2019), it may be inferred that CRF could also influence climbers´ attentional performance. This connection underscores the potential interplay between physical fitness and cognitive functions in climbing, suggesting that climbers' attentional advantages might partly be attributed to their superior cardiorespiratory conditioning.

Despite ample evidence of the attentional advantages of expert athletes in other sports, and the implication of attention in different aspects of climbing performance, research investigating the relationship between attention and climbing performance remain limited to date. Recognizing this gap, this Ph.D. Thesis will delve deeper into these aspects, examining how climbers' attentional performance can be even influenced by their CRF levels. This study aims to offer new insights into how physical and cognitive domains are integrated to optimize performance in this demanding sport.

Working Memory

From the perspective of the cognitive component skills approach, WM has been another cognitive function that has garnered attention in sports (Buszard et al., 2017; Vaughan & Laborde, 2020). Previously, researchers have studied the relationship between WM and athletic performance in a limited variety of sports, including basketball (Furley & Memmert, 2010; Vaughan & Laborde, 2020) and climbing (Heilmann, 2021; Whitaker et al., 2019). Unlike attention, consensus on whether elite athletes demonstrate superior WM performance in laboratory tasks compared to expert and novice remains unclear (Buszard et al., 2017; Vaughan & Laborde, 2020). Furley & Memmert (2010) investigated WM capacity in basketball players with the Corsi Block task, finding no significant differences when compared to non-athlete college students. In contrast, Vaughan & Laborde (2020) used the same task and found that athletes with greater expertise demonstrated significantly higher WM capacity compared to their less experienced counterparts.

In climbing, several studies employing the locomotor-cognitive dual-task paradigm have demonstrated the involvement of WM, highlighting its significance in the sport (Darling & Helton, 2014; Epling et al., 2018; Green et al., 2014; Green & Helton, 2011). Despite this, findings regarding expertise differences in climbing populations remains inconsistent, with some studies using the Corsi Block task to measure WM capacity (Heilmann, 2021; Whitaker et al., 2019). For example, Whitaker et al. (2019) reported no clear WM advantage for expert climbers, contrasting with Heilmann (2021) who observed a lower WM in expert compared to novice climbers. These contradictory findings have sparked debate, with researchers like Buszard et al. (2017) cautioning against the assumption that greater WM automatically translates to superior athletic performance. They argue for a sport-specific analysis of WM, asserting that a nuanced examination is crucial to fully understand how WM influences performance in different athletic disciplines. This underscores the complexity of cognitive functions in sports and necessitates detailed research to elucidate the specific role of WM in climbing performance.

Research in neuroscience has established the PFC as a pivotal area for WM processes (Bahmani et al., 2019; Chai et al., 2018; Fishburn et al., 2014). Using NIRS, scientist have been able to track cerebral oxygenation and neural activity during WM tasks in the PFC (Sato et al., 2013). Studies using NIRS indicate that individuals capable of loading more information into WM exhibit noticeable variations in O_2Hb and HHb levels in the PFC, indicative of greater neural activation due to cognitive load (Fishburn et al., 2014; Ogawa et al., 2014). Interestingly, a paradox emerges where those with higher WM capacity may show reduced PFC O_2Hb levels, reflecting a potential marker of neural efficiency in individuals with advanced cognitive capacities (Anderson et al., 2018). This Ph.D. Thesis will analyze these aspects to better understand the role of WM in sport climbing, particularly focusing on how it contributes to climbing performance through hemodynamic responses in the PFC.

Theoretical model focused on the expert performance approach

The expert performance approach, which focuses on examining athletes within the context of their specific sport or within an ecologically valid context, assess expertise differences in sport-specific cognition (Williams & Ericsson, 2005). Supporting this approach, Mann et al. (2007) conducted a meta-analytic review showing consistently that experts in their respective sports outperform non-experts across a range of tests designed to measure sport-specific cognitive abilities. These assessments encompass spatial memory, visual search, attention, perception, and decision-making skills related to sport-specific environmental information. This approach offers valuable insights into how cognitive functions contribute to athletic expertise, particularly when analyzed within the sport's unique requirements and challenges. In climbing, research has particularly focused on differences in sport expertise, centering on the short-term memory of climbers (Boschker et al., 2002; Heilmann, 2021; Whitaker et al., 2019). Studies have evidenced that expert climbers recall more holds on a climbing route (Boschker et al., 2002; Heilmann, 2021; Whitaker et al., 2019) and demonstrated greater accuracy in recalled motor sequences than less expert climbers (Whitaker et al., 2019). However, further research is needed within an ecologically valid context to understand how WM varies in real-world situations among climbers of different skill levels. Nonetheless, the absence of comprehensive assessment tools for a wide range of cognitive functions poses a significant obstacle. One of the primary challenges for the scientific community is the development of specific tools to accurately measure various cognitive functions. This is essential for capturing the diverse cognitive processes involved in athletic performance, beyond those directly related to the sport itself. To address the methodological challenges, this research will introduce an innovative tool designed to study WM in the context of climbing. This tool aims to bridge the gap between laboratory and field settings, providing insights into the cognitive processes that underpin climbing performance.

Emotional domain in climbing

In relation to the emotional domain, research agrees that fear of falling is a primary source of anxiety in climbers, negatively impacting their performance (Draper et al., 2008, 2010; Hodgson et al., 2009; Sheel, 2004), notably in women climbers (Baláš et al., 2017). However, studies indicate that elite or advanced climbers experience less anxiety during lead climbing, (Dickson et al., 2012; Fryer et al., 2012) hinting at emotional differences associated with expertise.

This fear, as an emotion, along with its associated symptoms such as anxiety, elicits physiological, behavioral, and cognitive responses that facilitate harm avoidance and ensure survival (Tovote et al., 2015). A broader understanding of fear and anxiety is mirrored in sports psychology, where various theoretical models explore how emotional regulation, particularly in response to fear and anxiety, affects athletic performance (Craig, 2009; Laborde et al., 2016).

Theoretical models focused on emotional intelligence

One such model focuses on EI - the ability to perceive, manage and reason with one’s own and others’ emotions effectively- (Salovey & Mayer, 1990). EI is also considered a personality trait associated with behavioral tendencies and self-perceived abilities to recognize and understand emotions, comprehend their impact on thoughts and behavior, as well as the strategies used to regulate them (Petrides & Furnham, 2001). Both construct of EI, whether as an ability or trait, have been linked to athletic success, indicating that proficient emotional management promotes athletes' adaptation, enhancing both their physical and psychological adjustment to their environment (Laborde et al., 2016). Moreover, differences in EI have been identified between open skill sports and closed skill sports, suggesting that the intrinsic characteristics of each sport are related to EI (Bal et al., 2011). Open skill sports require players to react in a dynamically changing, unpredictable, and externally-paced environment (e.g., basketball, tennis, fencing), whereas closed skill sports involve a more consistent, predictable, and self-paced environment for players (e.g., running, swimming, climbing) (Singer, 2000). In climbing, EI has primarily been examined to assess variances between men and women, with findings suggesting that male climbers rely more on recognizing and understanding emotional states to solve problems and achieve success in climbing compared to women (Marczak & Ginszt, 2017). However, understanding how EI varies among climbers of different skill levels and its impact on performance, particularly in managing fear and anxiety, is essential. This highlights the necessity for a deeper investigation into this domain, a gap that this Ph.D. Thesis aims to fill by examining the nuances of EI in climbers across various levels of expertise.

Theoretical models focused on interoceptive awareness

Another perspective recently supported in neuroscience is the interoception models (Craig, 2002), which illustrate how the body and mind interact in complex ways, mutually influencing each other, and ultimately manifesting and comprehending emotions. This model define IA as the recognition of bodily signals originating from emotions (Füstös et al., 2013; Mehling et al., 2009). IA plays a significant role in emotional experiences and is a crucial component for successful emotional regulation and anxiety management (Barlow et al., 2017). Although IA is extensively researched in clinical populations as part of emotional regulation in the treatment of anxiety (Kaczkurkin & Foa, 2015), to date, in the field of sports, only one study highlights the importance of IA in regulating perceived stress in athletes (Di Fronso et al., 2022). Moreover, although a few studies have focused on reducing anxiety through the use of relaxation techniques (Maynard et al., 1997) or top rope climbing (Aras & Ewert, 2016), no study to date has addressed anxiety in climbing from a perspective centered on emotional management. Given the prevalent fear of falling among climbers, especially women, investigating how IA can be leveraged for emotional regulation to enhance performance and manage anxiety in climbing is a need that this Ph.D. Thesis aims to explore.

AIMS

AIMS

The general aim of this Ph.D. Thesis was to enhance understanding of psychological parameters within cognitive, emotional, and brain activity domains among climbers of different levels, from recreational to elite, specifically examining how these factors interrelate and contribute to climbing performance.

Specific aims

1) To investigate the relationship between cognitive domains, especially attention and WM, and climbing ability, while accounting for other influencing factors (Study I and II).
2) To examine differences in WM capacity and PFC hemodynamic responses during a WM task between different ability groups in climbing and female and male (Study II).
3) To design and develop an innovative tool for assessing WM in the context of climbing to bridge laboratory research with field application (Invention).
4) To explore the emotional domain by assessing EI across climbers of different skill levels (Study III).
5) To assess the effect of a psychological training intervention focused on emotional regulation on anxiety levels and climbing performance in women climbers with fear of falling (study IV).

OBJETIVOS

El objetivo general de la presente Tesis doctoral fue mejorar la comprensión de los parámetros psicológicos dentro de los dominios cognitivos, emocionales y de actividad cerebral entre escaladores de diferentes niveles, desde recreativos hasta élites, examinando específicamente cómo estos factores se interrelacionan y contribuyen al rendimiento en la escalada.

Objetivos Espefícicos

1) Investigar la relación entre los dominios cognitivos, especialmente la atención y la memoria de trabajo, y la habilidad en la escalada, teniendo en cuenta otros factores influyentes (Estudio I y II).
2) Examinar las diferencias en la capacidad de memoria de trabajo y las respuestas hemodinámicas del córtex prefrontal durante una tarea de memoria de trabajo entre diferentes grupos de habilidad en la escalada y entre mujeres y hombres (Estudio II).
3) Diseñar y desarrollar una herramienta innovadora para evaluar la memoria de trabajo en el contexto de la escalada para conectar la investigación de laboratorio con la aplicación en el campo (Invención).
4) Explorar el dominio emocional evaluando la Inteligencia Emocional entre escaladores de diferentes niveles de habilidad (Estudio III).
5) Evaluar el efecto de una intervención de entrenamiento psicológico centrada en la regulación emocional sobre los niveles de ansiedad y el rendimiento en la escalada en mujeres escaladoras con miedo a caer (Estudio IV).

HYPOTHESES AND RESEARCH QUESTIONS

HYPOTHESES AND RESEARCH QUESTIONS

Based on the evidence previously presented, we hypothesize that psychological parameters across cognitive, emotional, and brain activity domains will vary significantly among climbers of different skill levels, from recreational to elite. This variation is expected to manifest in distinct patterns of attention, working memory, and EI, all of which are presumed to interrelate and contribute to climbing performance. Furthermore, we anticipate that interventions aimed at improving emotional regulation will not only reduce anxiety but also enhance overall climbing performance, particularly in individuals experiencing a fear of falling. This Ph.D. Thesis seeks to integrate these domains to provide a comprehensive overview of the psychological factors that distinguish climbing proficiency across varying levels of expertise.

The specific hypotheses of each specific aims are detailed below:

Specific Aim I.

Hypothesis for Study I: Given that attentional capacity is a critical cognitive function in climbing, it is hypothesized that there will be significant differences in attentional capacity among climbers of different skill levels.

Hypothesis for Study II: Considering that working memory is a crucial cognitive capacity for climbing performance, it is hypothesized that climbers of different skill levels will exhibit differences in working memory capacity.

Specific Aim II.

Hypothesis for Study II: Given that the prefrontal cortex is one of the cerebral correlates of working memory, it is expected that differences in working memory capacity will be reflected in the cerebral hemodynamics of the prefrontal cortex during task execution among climbers of varying skill levels and between genders.

Specific Aim III.

Hypothesis for Invention: It is proposed that the innovative tool developed for assessing working memory will provide reliable data that correspond with climbers' performance in the field, illustrating the tool's effectiveness in a practical climbing context.

Specific Aim IV.

Hypothesis for Study III: Considering that elite climbers are less affected by anxiety compared to novice and expert climbers, it is hypothesized that there will be significant differences in levels of Emotional Intelligence in relation to climbing skill level.

Specific Aim V.

Hypothesis for Study IV: Considering that anxiety impairs climbing performance and that women may be more impacted by anxiety, it is hypothesized that female climbers undergoing psychological training focused on emotional regulation to cope with the fear of falling will exhibit changes in interoceptive awareness, a reduction in anxiety, and an improvement in climbing ability. Additionally, it is hypothesized that the impact of psychological training will surpass that of physical training in enhancing interoceptive awareness, reducing cognitive and somatic anxiety, and enhancing self-confidence and climbing ability.

METHODOLOGY

METHODOLOGY

This section offers a detailed description of the materials and methods utilized in each of the studies incorporated into the Ph.D. Thesis. In brief, this Thesis provides a comprehensive analysis of the cognitive and emotional domains related to performance in sport climbing. The research delves into attention, WM capacity, EI, and the effects of psychological training, highlighting their importance in climbing performance. The findings are integrated into four distinct studies involving a total of 136 climbers (60 women), aged between 26 and 41 years old. Self-reported climbing ability served as the independent variable. The on-sight climbing ability ranging from 5+ to 8a+ was utilized in studies I, II, and IV. The red-point climbing ability, ranging from 6b to 8b+, was employed in study III. The recruitment of participants for each study was carried out in different stages through a call on social networks in accordance with the previously established objectives. The protocols for each study were conducted in accordance with the ethical standards outlined in the 1961 Declaration of Helsinki and were approved by the Research Ethics Committee.

The instruments used to assess the dependent variables, as well as the main analyses employed, are summarized in Table 1 and briefly detailed in the current section of this Ph.D. Thesis.

Table 1. General overview of the methodology followed in the studies and invention included in this Ph.D. Thesis.

Study/Invention	Design	Psychological variables	Participants	Independent variables	Methodology	Dependent variables	Main Statistical analysis
Cognitive Domain							
Study I**. Attentional differences as a function of rock climbing performance**	Cross-sectional	Attention	35 climbers (25 male; 10 female)	On-sight and red-point climbing ability	Self-reported climbing ability Signal Detection Task Determination Task	Accuracy of responses (ACC) Reaction Time (RT)	Linear regression analysis
Study II. **Cognitive function of climbers: an exploratory study of working memory and climbing performance**	Cross-sectional	Working Memory	28 climbers (23 male; 5 female)	On-sight climbing ability	Self-reported climbing ability eCorsi Task Near-Infrared Spectroscopy (NIRS)	Working Memory Capacity, Error Rate, Error Reaction Time, and Hit Reaction Time Prefrontal Cortex Oxygenation and De-oxygenation	ANOVA analysis Linear regression analysis. Correlation analysis.
Invention. **Autonomous and Portable System for Training Working Memory and Climbing Technique**	Invention: “Modelo de Utilidad”	Working Memory	-	-	Registration at the Oficina Española de Patentes y Marcas (OEPM)	Working Memory Capacity	-

Emotional Domain							
Study III. **Role of emotional intelligence on rock climbing performance**	Cross-sectional	Trait and ability - based Emotional Intelligence	42 climbers (28 male; 14 female)	Red-point climbing ability	Self-reported climbing ability Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT) Schutte Self-Report Emotional Intelligence Test (SSEIT)	Ability-based Emotional Intelligence Trait-based Emotional Intelligence	One-way analysis of covariance (ANCOVA) Linear regression analysis
Study IV. **Fear of falling in women: A psychological training intervention improves climbing performance.**	Quasi-experimental	Anxiety Climbing performance	31 female climbers	On-sight climbing ability	Control Group (n = 10); Psychological Training Group (n = 11); Physical Training Group (n = 10) Self-reported climbing ability Spanish version of the Revised Competitive State Anxiety Inventory-2 (CSAI-2 R) Spanish version of the Multidimensional Assessment of Interoceptive Awareness (MAIA)	Self-reported climbing ability Cognitive Anxiety Somatic Anxiety Self-Confidence Interoceptive Awareness	Repeated-measure ANCOVAs

The following sections are specifically dedicated to an elaborate exposition of the methodologies employed across the studies compiled in this Ph.D. Thesis. Each segment delineates the rigorous research protocols, participant selection criteria, experimental procedures, and statistical analyses that collectively underpin our empirical findings.

I

STUDY I. Attentional differences as a function of rock climbing performance.

Garrido-Palomino, I., Fryer, S., Giles, D., González-Rosa, J. J., & España-Romero, V. (2020). Attentional differences as a function of rock climbing performance. Frontiers in Psychology, 11(1550). https://doi.org/10.3389/fpsyg.2020.01550

STUDY I. Attentional differences as a function of rock climbing performance.

Participants and selection criteria

Thirty-five sports climbers (10 women) were recruited via a social network call to participate. All participants were healthy, were nonsmokers, and were not taking any vascular acting medication. Incluson criteria included a) being over 18 years old; b) having at least 2 years of climbing experience; c) At least three months of systematic climbing and training prior to the test. As exclusion criteria, the following will be established a) acute or terminal illness; b) myocardial infarction within three months prior to the start of the study; c) Unstable cardiovascular disease; d) medical prescription that prevents the completion of the tests; e) Injury or circumstance that prevents the proper completion of the tests (e.g. Color blindness); f) Not taking any type of ergogenic supplement that could influence this study.

Etical considerations and study protocol

Participants read and were informed about the objectives of the study and signed the consent form prior to participating in the study. The study protocol was approved by the University of Cadiz Committee for research involving human subjects before recruiting participants. Data collection was performed in accordance with the ethical standards set by the journal and the Declaration of Helsinki.

Two attention tasks (Signal Detection and Determination Tasks) were administered (counterbalanced) with a 30-min break between each, using a laptop (15 in., 1,366 × 768 color screen) running the Vienna Test System software version 26.04 (Schuhfried, Austria). In addition, participants completed an incremental treadmill cardiorespiratory exercise test to determine cardiorespiratory fitness. Participants were asked not to consume food for 4 h prior to testing and to avoid caffeine and exercise for a minimum of 12 h. All testing sessions were conducted in the same week, in an environmentally controlled exercise laboratory. The completion of the physical test and the attention task was counterbalanced.

Outcomes measures

Self-reported climbing ability

On-sight self-reported climbing ability was reported as the most difficult route completed without falls within the last 6-12 months.

Signal Detection Task

The Signal Detection Task (SIGNAL, 26.04 versions, Vienna Test System) was used to evaluate the accuracy of participants' response (AC) to a visual scanning and selective attention.

Determination Task

A modified version of the S12 Determination Task (DT, 32.00 version, Vienna Test Systems) was used to measure the speed of motor response, also called reaction time (RT)

Cardiorespiratory Fitness

Cardiorespiratory fitness (VO_{2max}) was assessed by an incremental treadmill cardiorespiratory exercise test using the athlete- led protocol (Draper & Marshall, 2014).

Confounding variables

The following variables were considered as potential confounders: sex, age, climbing experience (years), and VO_{2max} for cardiorespiratory fitness.

Statistical Analyses

Normal distributions, and homogeneity of variances for continues variables was analyzed using Shapiro– Wilk test. Potential sex differences for each dependent variable were analyzed by t-test for continuous variables and chi-square tests for categorical variables. Pearson correlations were used to examine the relationship between attention tasks and descriptive climbing parameters. Linear regression was performed to examine the association between climbing ability (on-sight or red-point) and attention task (AC or RT). Covariates were included in the regression analyses by using three levels of adjustment models: Model 1, unadjusted; Model 2, adjusted for sex, age, and climbing experience (years climbing); and Model 3, adjusted for sex, age, climbing experience (years climbing), and CRF. Statistical analyses were performed using STATA version 14.0 (Stata Corp College Station, TX, United States). Statistical significance was set at $p < 0.05$.

II

STUDY II. Cognitive function of climbers: an exploratory study of working memory and climbing performance.

Garrido-Palomino, I; Giles, D; Fryer, S; González-Montesinos, J.L.; España-Romero, V. Cognitive function of climbers: an exploratory study of working memory and climbing performance. Spanish Journal of Psychology. **In Press.**

STUDY II. Cognitive function of climbers: an exploratory study of working memory and climbing performance.

Participants and selection criteria

Twenty-eight rock climbers (5 Female) were recruited by social network advisement volunteered to participate in the study. All participants met the inclusion criteria, which included a) having at least two years of climbing experience, b) undergoing at least three months of regular climbing prior to the study, c) being over 18 years old, and d) having an absence of injury or conditions that would not be advisable for physical exertion. The exclusion criteria included a) history of neurological or psychiatric disorders, b) the use of medications that could affect vascular function, as well as c) substance abuse or dependence.

Etical considerations and study protocol

The study received ethical approval from the University Ethics Committee. The data for this study were collected from the High-Performance International Rock-Climbing Research Group (C-HIPPER).

Outcomes measures

Body composition and socio-demographic characteristics

Weight, height, and body mass index (BMI) were measured to describe the sample and a sociodemographic questionnaire was administered to collect climbing experience (yrs.), climbing days per week, and educational level from participants.

Self- Reported Climbing Ability

On-sight self-reported climbing ability was reported as the most difficult route completed without falls within the last 3-6 months.

Working Memory

The digital version of the Corsi-block task (eCorsi) was administered using an experimentally validated open-source software system called PEBL (Mueller & Piper, 2014). The outcomes included WM Capacity, which refers to the number of blocks in the longest correctly reproduced sequence (span score); Error Rate, representing the total number of incorrect responses; Hit Reaction Time for corrects answers, measuring the speed of response for correctly reproduced sequences in milliseconds; and Errors Reaction Time, capturing the speed of response for incorrect answers in milliseconds.

Prefrontal Cortex Perfusion

PFC perfusion was monitored using continuous-wave NIRS, NIRO-200NX (Sato et al., 2013). The assessed parameters include the concentration changes in O_2Hb, HHb, and tHb -referred to as perfusion, as well as the TOI.

Confounding variables

Sex, age, climbing experience, and education level were considered confounding variables known to be associated with WM according to Archer et al., (2018). Additionally, any variables that exhibited a change in β coefficients greater than 10% were included in the regression analyses.

Statistical Analyses

For statistical analyses, the sample was divided into expert climbers (<75th percentile) and elite climbers (>75th percentile) based on their sex-specific on-sight climbing ability at the 75th percentile. The Shapiro-Wilk goodness-of-fit test was used to assess the normal distribution of the data, while Levene's test was employed to examine equal variance. Non-normal variables were transformed for subsequent analyses.

Analysis of Variance (ANOVA) was performed to assess differences among quantitative descriptive variables. In cases where data did not meet ANOVA assumptions, the non-parametric Kruskal-Wallis test was employed. For categorical variables, the Fisher's exact test was used to examine differences across categorical variables.

Linear regression analysis was applied to analyse the relationship between WM outcomes and Climbing Ability. Additionally, four adjustment models were used to study the effect of confounding variables such as Model 1 was adjusted for sex, Model 2 was adjusted for sex and age, Model 3 was adjusted for sex and climbing experience, and Model 4 was adjusted for sex and education level.

Pearson correlation analyses were conducted to assess the relationship between WM load across trials and changes in O_2Hb and HHb levels in both the left and right PFC. Spearman correlation analyses were applied to variables that did not follow a normal distribution. Additionally, Fisher's exact test was used to analyze categorical differences between PFC hemodynamic responses during the WM task and climbing ability groups (Expert vs. Elite) and sex (Female vs. Male). This was complemented by ANOVA, and where necessary due to non-normal distributions, the non-parametric Kruskal-Wallis test.

All statistical analyses were performed using STATA version 13.1 (Stata Corp, College Station, TX, USA).

III

INVENTION. Autonomous and Portable System for Training Working Memory and Climbing Technique.

Garrido-Palomino, I. & España-Romero, Vanesa (2023). Sistema autónomo y portable para el entrenamiento de la memoria de trabajo y la técnica en escalada. U202231081. Oficina Española de Patentes y Marcas (OEPM). Volumen II: Invenciones: Nº. 6512, Boletín Oficial de la Propiedad Industrial, 10 de octubre de 2023.

INVENTION. Autonomous and Portable System for Training Working Memory and Climbing Technique

The methodology followed for the development of the patent in Spain involved several key stages. Initially, an extensive review of scientific and technical literature pertaining to climbing, WM, and portable technologies was conducted. Subsequently, a design and development process ensued, encompassing the conceptualization of the autonomous and portable system, as well as the engineering of its components and the programming of its software to measure WM in an ecologically valid environment. Furthermore, a detailed analysis was conducted on previously registered methods of analysis inventions, considered closely related to the object of the invention, to verify that none of the registered inventions, taken separately or in combination, enable the training of WM or climbing technique. Notably, the patented invention was classified as a "modelo de utilidad", a type of intellectual property protection granted to inventions offering practical solutions to technical problems. Finally, the necessary documentation was prepared, and the patent application was submitted to the Oficina Española de Patentes y Marcas (OEPM), adhering to the procedures and requirements outlined by intellectual property law and specific patent regulations in Spain.

IV

STUDY III. Role of emotional intelligence on rock climbing performance.

Garrido-Palomino, I., & España-Romero, V. (2019). Role of emotional intelligence on rock climbing performance. RICYDE: Revista Internacional de Ciencias Del Deporte, 15(57), 284–294. https://doi.org/10.5232/ricyde2019.05706

STUDY III. Role of emotional intelligence on rock climbing performance

Participants and selection criteria

The present study utilized a cross-sectional design. Forty-two experienced sport climbers (14 female and 28 males) were recruited via a social network call to participate. Incluson criteria included a) being over 18 years old; b) having at least 2 years of climbing experience; c) At least three months of systematic climbing and training prior to the test. As exclusion criteria, the following will be established a) acute or terminal illness; d) medical prescription that prevents the completion of the tests.

Etical considerations

The study protocol was performed in accordance with the ethical standards established in the 1961 declaration of Helsinki and was approved by the Research Ethics Committee from the University of Cadiz. Participants were provided with a thorough verbal explanation of the study's nature and objectives, following which written informed consent was obtained.

Outcomes measures

Sociodemographic characteristics

The age, climbing experience, and climbing frequency were collected through a brief interview with the participants. Body weight was measured using a multifrequency bioimpedance scale (SECA, Vogel & Halke GmbH & CO. KG, Hamburg, Germany; precision 0.1 kg), and height was measured in the Frankfurt plane using a telescopic height measuring instrument (Norton, 2018). Participants were barefoot and wearing only underwear during the measurements.

Self-reported climbing ability

Red-point self-reported climbing ability was reported as the most difficult red-point (pre-practiced) route completed without falls within the last 6-12 months.

Ability-based Emotional intelligence

Ability-based Emotional intelligence was measured by using a Spanish translation of the Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT) (Extremere et al., 2006).

Trait-based Emotional Intelligence

The Schutte Self-Report Emotional Intelligence Test (SSEIT) was applied to measure the Trait-based Emotional Intelligence (Schutte et al., 1998; Austin et al., 2004).

Confounding variables

The potential confounding variable considered was age for the analysis.

Statistical Analyses

The sex-specific 75^{th} percentile of red-point climbing ability was used to divide the sample into expert ($\leq 75^{th}$) and elite ($> 75^{th}$) climbers for further analyses. Normal distributions, and homogeneity of variances for categorical variables was analyzed using the Kolmogorov-Smirnov test. Differences between male and female as well as expert and elite climbers in EI parameters in both questionnaires were analyzed by one-way analysis of variance (ANOVA). The analyses were also adjusted by age using one-way analyses of co-variance (ANCOVA). Linear regression analyses were performed to examine the relationship between EI and sex as well as EI and climbing performance. Statistical analyses were performed using STATA version 14.0 (Stata Corp, College Station, TX, USA). Statistical significance was set at $p < .05$.

V

STUDY IV. Fear of falling in women: A psychological training intervention improves climbing performance.

Garrido-Palomino, I., & España-Romero, V. (2023). Fear of falling in women: A psychological training intervention improves climbing performance. Journal of Sports Sciences, 41(16), 1518–1529. https://doi.org/10.1080/02640414.2023.2281157

STUDY IV. Fear of falling in women: a psychological training intervention improves climbing performance.

Participants and selection criteria

A total of 44 recreational women climbers were recruited through personal invitations, climbing clubs, and social media advertisements and expressed interest in voluntarily participating in the High-Performance International Rock-Climbing Research (C-HIPPER) study. Inclusion criteria were defined as follows: (1) being biologically a woman, (2) reporting to experience fear of falling during lead climbing, (3) having at least one year of climbing experience, and (4) being capable of on-sight lead climbing. On the contrary, exclusion criteria encompassed: (1) simultaneously participation in another clinical trial, (2) any medical prescription that prohibit climbing, (3) presence of an acute or terminal illness, and (4) currently receiving psychological training for climbing.

Etical considerations and study protocol

Prior to recruitment, the study protocol was approved by the Ethics Committee (PEIBA code 1739-N-21), and data collection was conducted in accordance with the ethical standards set by the journal and, the Declaration of Helsinki.

The participants were subsequently assigned to the three groups according to their back-ground and preferences. During the course of the study, 10 participants dropped out. The Psychological Intervention Group (PG) consisted of 11 participants who expressed a preference for starting psychological training due to fear of falling and were not undergoing climbing training with a sports specialist. The Physical Training Group (TG) comprised 10 participants who were already following a specialised climbing training programme with a sports specialist. The Control Group (CG) consisted of 10 participants who did not undergo any specific training, either psychological or physical, throughout the study period.

The psychological intervention received by the PG wasfocused on emotion regulation using IA to cope with anxiety (Füstös et al., 2013; Price & Hooven, 2018). Participants in both the TG and CG were instructed to maintain their regular climbing activities throughout the study. Pre-test assessments of climbing ability, anxiety, self-confidence, and interoceptive awareness were conducted after group allocation. Post-test measures were administered after the psychological training intervention for the PG and four months after recruitment for the TG and CG.

Outcomes measures

Self-reported climbing ability

On-sight self-reported climbing ability was reported as the most difficult route completed without falls within the last 3-6 months.

Anxiety and self-confidence

Cognitive and somatic anxiety levels and self-confidence were measured using the Spanish version of the Revised Competitive State Anxiety Inventory-2 (CSAI-2 R) (Andrade et al., 2007).

Interoceptive Awareness

IA was assessed using the validated and reliable Spanish version of the Multidimensional Assessment of Interoceptive Awareness (MAIA) (Valenzuela-Moguillansky & Reyes-Reyes, 2015).

Confounding variables

We included variables Not-Distracting and Noticing as covariates in our analysis because exhibited large effect sizes and statistical power greater than 50%, indicating their potential impact on the intervention. Moreover, we included additional variables such as Outdoor Climbing Days per Week, Years Climbing, Not-Worrying, Emotional Awareness, Self-Regulation, and Body Listening as covariates in subsequent analyses to account for their effects. These variables displayed small to medium effect sizes, indicating their potential influence on the outcomes being studied.

Statistical Analyses

The normality of distributions was confirmed using Shapiro-Wilk's test, while homogeneity of variances was confirmed with the Breusch-Pagan test.

We conducted an a priori statistical power analysis using G*Power software (Faul et al., 2007) with a sample size of 31 participants to ensure adequate statistical power and address baseline differences between groups for our primary outcome measure at baseline. Additionally, we performed analysis of covariance (ANCOVAs) to mitigate potential confounding variables and enhance the reliability of our intervention assessment. These ANCOVAs focused on variables with medium to large effects in pre-test ANOVAs, providing a robust framework for evaluating the intervention's impact.

To evaluate the effect of time and the interaction between group factors (Group × Time) on main outcomes were conducted a repeated measures ANOVA. Post-hoc Bonferroni comparisons assessed the inter-group for the main outcomes from pre- to post-intervention. Post-hoc pairwise t-test comparisons were used to explore the source of differences in the pre-post scores between groups for each significant ANOVA.

Statistical analyses were performed using STATA version 16.0 (Stata Corp, College Station, TX, USA).

RESULTS

RESULTS

In this section, the identifying data, results, and discussion of the four publications and the invention included in the Ph.D. Thesis are presented in the order to address the main research questions. All studies have been published in impact factor journals indexed in the top four quartiles (Q1-Q4) of the Journal Citation Reports. Specifically, the articles are published in the Journal of Sports Sciences (Q1), the Frontiers in Psychology journal (Q2), the Spanish Journal of Psychology (Q3), and the International Journal of Sport Sciences (RICYDE) (Q4). Additionally, the utility model has been published in Volume II: Inventions. No. 6512, of the Boletín Oficial de la Propiedad Industrial, dated October 10, 2023. An overview of the main results obtained in each of the studies is summarized below in **Table 2**.

Table 2. Overview of the main results obtained in each of the studies included in this Ph.D. Thesis.

STUDY / INVENTION	OUTCOMES	MAIN RESULTS
Cognitive domain		
Study I. **Attentional differences as a function of rock climbing performance**	Accuracy of Responses (AC)	▪ Linear regression analysis revealed that AC was positively related with the highest on- sight ability (β = .371; *p* = 0.028). ▪ Sex, age, climbing experience (years), and VO_{2max} appear to be predictors of the relationship between AC and on- sight ability (β = 0.388; p = 0.031), explaining 34.3% of the variance (R^2) ▪ There was no significant relationship between AC and red-point ability (β = 0.286; *p* = 0.064). No significant differences were found between male and female participants for AC.
	Reaction Time (RT)	▪ Linear regression analysis revealed that there were no significant relationships between RT and on-sight (β = −0.102 to 0.020; *p* = 0.304 to 0.680) or red-point ability (β = −0.089 to 0.007; *p* = 0.306 to 0.893). ▪ No significant differences were found between male and female participants for RT.
Study II. **Cognitive function of climbers: an exploratory study of working memory and climbing performance**	Working memory outcomes	▪ Linear regression analysis revealed no significant associations between WM Capacity and Climbing Ability (F (1, 26) = 3.77, p = .063, R^2 = .127). ▪ Significant association between WM capacity and climbing ability were found after adjusted by Sex (F (2, 25) = 3.56, t = -2.64, p = .014), Sex in conjunction with Age (F (3, 24) = 2.33, t = -2.38, p = .026), Sex combined with Climbing Experience (F (3, 23) = 2.20, t = -2.46, p = .022), as well as Sex along with Education Level (F (3,23) = 2.08, t = -2.20, p = .038). ▪ Regression analysis revealed positive significant associations between Error Reaction Time and Climbing Ability (F (1, 26) = 9.21, p = .005, R2 = .262). This significant association persisted across all models after adjusting for confounding factors. ▪ Error Rate was negatively associated with Climbing Ability when Sex and Education Level were taking into account in the regression analysis ((F (3, 24) = 2.30, t = -2.30, p = .03). ▪ Non-significant associations were found for Hit Reaction Time and Climbing Ability (p > .05).
	Hemodynamic outcomes	▪ A significant positive correlation was found between WM load and O_2Hb in both the right (r = .537; *p* < .001) and left PFC (r = .505; *p* < .001) across each trial. Conversely, a negative correlation was observed between WM load and HHb levels, for the right PFC (r = -.500; *p* < .001) and for the left PFC (rho = -.595; *p* < .001), across each trial.

		▪ Significant differences were found between Expert and Elite climbers in tHb levels at Fp1 (Mean Differences (MD) = -1.18; 95% Coefficient Interval (CI) = [-2.28, -.079]; $p = .037$), and HHb levels in both Fp1 (MD = -.80; 95% CI = [-1.43, -.71]; $p = .015$) and Fp2 (MD = - .78; 95% CI = [-1.34, - .23]; $p = .008$) during the WM task. ▪ Sex differences were also observed in HHb levels at Fp1 (MD = .75; 95% CI = [- .06, 1.56]; $p = .025$) and Fp2 (MD = 1; 95% CI = [.33, 1.67]; $p = .005$).
Invention. **Autonomous and Portable System for Training Working Memory and Climbing Technique**		▪ An innovative tool capable of assessing and training visuospatial working memory on any indoor climbing wall, as well as analyzing and training technique through the placement of inertial systems on different body areas, enables the recording of kinematic variables.
Emotional domain		
Study III. **Role of emotional intelligence on rock climbing performance**	Ability-based Emotional Intelligence	▪ Advanced climbers had a significantly higher measure of \`Facilitation Thought´ compared to Elite climbers (110.4 ± 10.6 vs. 102.9 ± 11.8, respectively). The same results were found when analyses were performed adjusted by age. ▪ Linear regression analyses adjusted for age revealed that \`Facilitation Thought´ was inversely associated with the highest red-point ability (b: -7.04 and 95% CI: -14.19 to -0.10; $p < 0.05$). The percentage of variance (R^2) explained by self-reported grade was 14.5%.
	Trait-based Emotional Intelligence	▪ Expression of Emotions' and 'Regulation of Emotions' were significantly higher in males than females (55.6 ± 5.2 and 43.4 ± 3.5, respectively), however, the significance disappeared when adjusted for age.
Study IV. **Fear of falling in women: A psychological training intervention improves climbing performance.**	Anxiety outcomes	▪ Significant differences were found after psychological intervention (PG) in Climbing Ability ($p < .01$), Cognitive ($p < .001$), and Somatic Anxiety ($p < .001$), and Self-Confidence ($p < .001$). ▪ TG exhibited pre-post significant differences in Climbing Ability ($p < .05$), Cognitive ($p < .01$), and Self-Confidence ($p < .05$).
	Interoceptive awareness (IA) outcomes	▪ Significant differences were found after psychological intervention (PG) in IA subscales such as Noticing ($p < .05$), Attention Regulation ($p <.01$), Self-Regulation ($p < .001$), Body Listening ($p < .001$) and Trusting ($p < .01$). ▪ TG showed significant differences in IA subscales such as Noticing ($p < .05$), Attention Regulation ($p < .05$) and Self-Regulation ($p < .05$) ▪ All evaluated IA parameters remained unchanged for the CG ($p > 0.05$), except for the Not-Distracting subscale, which showed a significant change ($p = .026$).

Group comparison	▪ Psychological Groups participants experienced an average increase of 54.5% in on-sight climbing ability, in contrast to a 6.8% increase in the TG. Conversely, the GC group experienced a 6% decrease in on- sight climbing ability. ▪ Repeated-measures ANOVA revealed a significant Time x Group interaction for Climbing Ability (F(2,28) = 14.23, p < .001, η_p^2 = .50), Cognitive Anxiety (F(2,28) = 8.63, p = .001, η_p^2 = .38), Somatic Anxiety (F(2,28) = 9.98, p = .005, η_p^2 = .29), and Self-Confident (F(2,28) = 26.87, p < .001, η_p^2 = .66), as well as for several IA subscales, such as the Noticing (F (2, 28) = 3.78, p = .035, η_p^2 = .21); Self-Regulation (F (2, 28) = 8.43, p = .001, η_p^2 = .37), Body Listening (F (2, 28) = 16.99, p < .001, η_p^2 = .55) and Trusting scores (F (2, 28) = 6.93, p < .003, η_p^2 = .33). ▪ Greater effect sizes were observed in the Psychological Training Group (PG) compared to the Treatment Group (TG) in the improvement of climbing ability, cognitive and somatic anxiety, self-confidence, as well as outcomes related to interoceptive awareness such as self-regulation, body listening, body trusting, noticing, and attention regulation.

The subsequent sections are devoted to a comprehensive presentation of the results obtained from the studies included in this Ph.D. Thesis. Each subsection delves into the detailed findings, providing insights into the observed trends, significant outcomes, and noteworthy patterns revealed through meticulous data analysis. These results serve to elucidate the key findings and contribute to a deeper understanding of the cognitive and emotional domain under investigation.

I

RESULT I. Attentional differences as a function of rock climbing performance (Study I).

Garrido-Palomino, I., Fryer, S., Giles, D., González-Rosa, J. J., & España-Romero, V. (2020). Attentional differences as a function of rock climbing performance. Frontiers in Psychology, 11(1550). https://doi.org/10.3389/fpsyg.2020.01550

Attentional differences as a function of rock climbing performance

The main results obtained regarding Aim 1, which focused on investigating the relationship between attention and climbing ability while accounting for other influencing factors, are detailed below.

Descriptive outcomes

Participants had a mean age of 34.7 years and a mean on-sight climbing ability of 7a (French scale), as shown in **Table 3**. Males were younger, heavier, and taller than females ($p < .05$). Moreover, males demonstrated superior on-sight and red-point climbing abilities as well as higher levels of CFR compared to females ($p < .001$ in all cases). The average climbing experience was similar between both sexes.

Table 3. Mean (SD) of the anthropometric, demographic, physical fitness and performance data in the care tasks of the participants of Study I.

	All (n=35)	Male (n=25)	Female (n=10)
Age (yrs)	34.7 (6.2)	33.5 (6.5)	37.9 (4.2) *
Mass (kg)	64.5 (8.6)	68.3 (6.7)	55.2 (5) +
Height (cm)	171.5 (8)	173.7 (8)	166 (4.9) +
Experience (years)	11.1 (7)	11.5 (7.6)	10.1 (5.7)
Self-reported climbing ability			
Best 6-month on-sight grade (French)	7a (3)	7a+ (2.9)	6b+ (1.6) *
Best 6-month red-point grade (French)	7a+ (3.6)	7b (3.7)	6c+ (1.6) *
Treadmill measures			
Cardiorespiratory fitness (mL·kg·min-1)	48.6 (5.3)	50.7 (4.9)	45.1 (4.6) *
Heart rate (bpm)	186.4 (10.5)	188.0 (10.9)	182.6 (8.9)

*$P < .05$; +$P < .001$

Main outcomes

Mean attentional control (AC) and RT measures for all participants in the attention tasks are displayed in **Table 4**. There were no significant differences observed between male and female participants in any attention tasks, including the SIGNAL and DT tasks.

Table 4. Mean (SD) Attention tasks [accuracy of response (AC) and reaction time (RT)] for all participants and by sex of Study I.

	All (N=35)	Male (N=25)	Female (N=10)
Accuracy of response (%)	87.6 (6.1)	88.8 (5.7)	84.8 (6.1)
Reaction time (msec)[a]			
Trial 1	673.03 (50.59)	669.13 (56.4)	682 (34.58)
Trial 2	657.88 (48.07)	650.87 (49.99)	674 (41.15)
Trial 3	665.15 (46.65)	660 (46.71)	677 (46.68)
Total	665.8 (43.6)	660 (46.8)	679 (33.5)

[a]Two daltonic participant were excludes from reaction time analyses, n=33 (23 males).

In relation to attentional control assessed by the Signal task, the association between AC and self-reported on-sight climbing ability was examined across various linear regression models, as shown in **Table 5**. The analysis revealed a positive correlation between AC (measured by the Signal detection task) and the highest self-reported on-sight ability (β = .388; *p* = .031).

Table 5. Relationship between accuracy of response (AC; dependent variable) and self-reported on-sight climbing ability (independent variable) in 35 experienced climbers of Study I.

	β	*P*	R^2	R^2 *adj*
Model 1	.371	***.028***	.134	.112
Model 2	.278	*.161*	.191	.083
Model 3	.388	***.031***	.343	.225

Note. Model 1: unadjusted; Model 2: sex, age and climbing experience (years); Model 3: sex, age, climbing experience (years) and $\bar{V}O_{2max}$. β = beta, regression equation; LCI= lower confidence interval (95%); UCI= upper confidence interval (95%).

However, as demonstrated in **Table 6**, no significant relationship was observed between AC and self-reported red-point ability (β = .286; *p* = .064).

Table 6. Relationship between accuracy of response (AC, dependent variable) and self-reported red-point climbing ability (independent variable) in 35 experienced climbers of Study I.

	β	*P*	R^2	R^2 *adj*
Model 1	.308	*.072*	.095	.067
Model 2	.170	*.182*	.160	.047
Model 3	.286	*.064*	.298	.172

Note. Model 1: unadjusted; Model 2: sex, age and climbing experience (years); Model 3: sex, age, climbing experience (years) and $\bar{V}O_{2max}$. *β* = beta, regression equation.

The relationship between RT and self-reported on-sight and red-point ability, measured by the DT task and analyzed across various linear regression models, are presented in Tables 7 and 8. The analyses revealed no significant relationships between RT and self-reported on-sight (β = −.102 to .020; *p* = .304 to .680) or red-point ability (β = −.089 to .007; *p* = .306 to .893).

Table 7. Relationship between reaction time (RT; dependent variable) and self-reported on-sight climbing ability (independent variable) in 33 experienced climbers of Study I.

RT	β	p	R^2	R^2 *adj*
Model 1				
Trial 1	-.086	.632	.008	-.025
Trial 2	-.075	.680	.006	-.027
Trial 3	-.102	.570	.011	-.021
Model 2				
Trial 1	-.033	0.304	.154	.033
Trial 2	.015	.388	.133	.009
Trial 3	-.033	.519	.106	-.022
Model 3				
Trial 1	-.029	.442	.155	-.002
Trial 2	.020	.535	.134	-.026
Trial 3	-.024	.645	.111	-.053

Note. Model 1: unadjusted; Model 2: sex, age and climbing experience (years); Model 3: age, climbing experience (years) and VO_{2max}; β = beta, regression equation; RT: reaction time

Table 8. Relationship between reaction time (RT; dependent variable) and self-reported red-point climbing ability (independent variable) in 33 experienced climbers of Study I.

	β	p	R^2	R^2 *adj*
Model 1				
Trial 1	-.024	.893	.001	-.032
Trial 2	-.051	.780	.003	-.030
Trial 3	-.089	.621	.008	-.024
Model 2				
Trial 1	-.017	.306	.153	.032
Trial 2	.007	.389	.133	.009
Trial 3	-.066	.506	.108	-.019
Model 3				
Trial 1	-.010	.444	.155	-.003
Trial 2	.014	.536	.134	-.026
Trial 3	-.052	.637	.113	-.051

Note. Model 1: unadjusted*;* Model 2: sex, age and climbing experience (years); Model 3: sex, age, climbing experience (years) and VO_{2max}; β = beta, regression equation.

II

RESULT II. Cognitive function of climbers: an exploratory study of working memory and climbing performance (Study II).

Garrido-Palomino, I; Giles, D; Fryer, S; González-Montesinos, J.L.; España-Romero, V. Cognitive function of climbers: an exploratory study of working memory and climbing performance. Spanish Journal of Psychology. **In Press.**

Cognitive function of climbers: an exploratory study of working memory and climbing performance

Below are the main results related to investigating the relationship between WM and climbing ability, while considering other influencing factors, as well as examining differences in WM capacity and prefrontal cortex (PFC) hemodynamic responses during a WM task between different ability groups in climbing and between females and males, according to our Aims 1 and 2.

Descriptive outcomes

As shown in **Table 9**, participants had a mean age of 37.5 years, with an average climbing experience of 14 years, ranging between 3 to 30 yrs. The mean on-sight climbing ability was 6c+ on the French scale, ranging from 5+ to 7c+. Specifically, Expert climbers reported climbing abilities ranging from 5+ to 7a+, while Elite climbers ranged from 6c to 7c+ in Elite climbers (75^{th} percentile, 7a+). Among Male participants, climbing ability ranged from 6a+ to 7b for Experts, and from 7b+ to 7c+ for Elites, with the 75^{th} percentile at 7b. Female participants reported climbing abilities ranged from 5+ to 6c for Expert and from 6c+ to 7a for Elite, with the 75^{th} percentile at 6c. Onsight climbing ability was significantly higher for Elite compared to Expert (p < .001) and for Male compared to Female (p < .001). Additionally, Males climbed significantly more days per week than Females (p < .05). Fisher's exact tests revealed no significant differences concerning to Education Level between Expert and Elite (p = .689) or between Sex (p = .355).

Table 9. Descriptive Characteristics, Working Memory Task Measures (mean ± standard deviation), and Analyses of Variance of the Entire Sample, Stratified by Climbing Ability and Sex

	All sample (n = 28)	**Expert** (n = 19)	**Elite** (n = 9)	**F** $_{(1,25)}$	***p***	**Female** (n = 5)	**Male** (n = 23)	**F** $_{(1,25)}$	***p***
Age (yrs.)	37.5 ± 6.6	37.3 ± 7.0	37.9 ± 6.3	.04	.834	38.1 ± 3.8	37.3 ± 7.3	.06	.811
Weight (kg)	69.9 ± 10.9	72.9 ± 10.7	64.1 ± 9.3	4.35	.047	55.4 ± 5.4	73.2 ± 9.0	17.47	< .001
Height (m)	172.8 ± 8.4	173.4 ± 6.8	171.6 ± 11.3	.25	.622	159.8 ± 4.6	175.7 ± 5.9	31.87	< .001
Body Mass Index (kg/m2) ^	23.4 ± 3.2	24.2 ± 3.4	21.7 ± 1.2	4.78	.038	21.7 ± 2.2	23.8 ± 3.3	1.86	.184
Education Level (%) [a]	39.3	44.4	30	.689[b]		16.7	45.5	.355[b]	
Climbing Experience (yrs)^	14.0 ± 9.3	12.1 ± 8.6	17.6 ± 10.0	1.91	.179	11.7 ± 9.5	14.6 ± 9.4	1.23	.277
Climbing Days per Week	1.8 ± .9	1.9 ± .9	1.6 ± .8	.76	.391	1.2 ± .8	2.0 ± .8	4.51	.043
On-sight Climbing Ability range (IRCRA scale)	16.27 ± 3.27	14.84 ± 2.67	19 ± 2.53	16.40	< .001	13.16 ± 2.92	17.09 ± 2.89	8.71	.007
Working Memory measures									
Working Memory Capacity (Span score)	5.6 ± .8	5.8 ± .8	5.2 ± .7	3.15	.087	5.5 ± .9	5.6 ± .8	.10	.754
Error Rate (Number of incorrect responses)	3.0 ± .9	3.2 ± .8	2.7 ± 1.0	3.77	.063	3.0 ± 1.2	3.0 ± .9	1.09	.306
Hit Reaction Time (Milliseconds)	590.3 ± 116.3	582.2 ± 111.8	607.5 ± 130.5	.28	.601	559.7 ± 54.3	597.0 ± 125.7	.41	.527
Error Reaction Time (Milliseconds)	655.4 ± 195.3	608.6 ± 194.4	754.1 ± 165.8	3.73	.064	551.5 ± 77.3	677.4 ± 195.3	1.77	.195

[a] Participant with university studies; [b] Fisher exact test analysis; ^ Inverse square root transformation
Note: p-values for comparisons between climbing ability groups and sex are based on ANOVA for continuous variables and Fisher exact test for categorical variables.

Main outcomes

Working Memory

The analysis revealed no significant associations between WM Capacity and Climbing Ability (F (1, 26) = 3.77, p = .063, R^2 = .127) (see **Table 10** and **Figure 1**). However, upon further examination of the influence of confounding factors, significant predictors of the association between WM capacity and climbing ability were found. These were Sex (F (2, 25) = 3.56, t = -2.64, p = .014), Sex in conjunction with Age (F (3, 24) = 2.33, t = -2.38, p = .026), Sex combined with Climbing Experience (F (3, 23) = 2.20, t = -2.46, p = .022), as well as Sex along with Education Level (F (3,23) = 2.08, t = -2.20, p = .038).

Comparable results were obtained when analysing the association between WM measurements and Climbing Ability exclusively in Male participants (n = 23). For instance, the association between WM Capacity and Climbing Ability was F (1, 21) = 10.87, p = .003, R^2 = .341.

Regression analysis revealed positive significant associations between Error Reaction Time and Climbing Ability (F (1, 26) = 9.21, p = .005, R^2 = .262). This significant association persisted across all models after adjusting for confounding factors: Model 1 (F (2, 25) = 4.46, t = 2.60, p = .016); Model 2 (F (3, 24) = 2.86, t = 2.40, p = .025); Model 3 (F (3, 23) = 5.52, t = 3.78, p = .001); Model 4 (F (3, 23) = 2.79, t = -2.21, p = .037). Error Rate was negatively associated with Climbing Ability when Sex and Education Level (Model 4) were taking into account in the regression analysis ((F (3, 24) = 2.30, t = -2.30, p = .03). Non-significant associations were found for Hit Reaction Time and Climbing Ability (p > .05).

Table 10. *Multiple Lineal Regression Coefficients Examining the Relationship of Working Memory and Climbing Ability.*

		b	β	95% IC		*t*	*p*	R^2	Adj R^2
				LL	UL				
	Linear regression model								
Working Memory Capacity (Span score)	Unadjusted	- .356	- .088	- .18	.01	-1.94	.063	.127	.093
	Model 1. Adjusted for sex	- .558	- .138	- .25	- .03	-2.64	.014*	.222	.159
	Model 2. Adjusted for sex and age	- .535	- .132	- .25	- .02	-2.38	.026*	.225	.129
	Model 3. Adjusted for sex and climbing experience (years)	- .581	- .153	- .27	- .02	-2.41	.024*	.218	.116
	Model 4. Adjusted for sex and education level	- .499	- .118	- .23	- .01	-2.20	.038*	.213	.111
Error Rate (Number of incorrect responses)	Unadjusted	- .210	- .06	- .16	-.05	-1.09	.285	.04	.007
	Model 1. Adjusted for sex	- .300	- .081	- .21	.05	-1.29	.207	.155	.091
	Model 2. Adjusted for sex and age	- .350	- .095	-.23	.04	-1.43	.167	.081	-.034
	Model 3. Adjusted for sex and climbing experience (years)	- .332	- .090	- .24	.06	-1.22	.234	.064	-.058
	Model 4. Adjusted for sex and education level	- .408	- .110	- .24	.02	-1.71	.101	.127	.013
Error Reaction Time (Milliseconds)	Unadjusted	.511	30	9.68	50.32	3.04	.005*	.262	.233
	Model 1. Adjusted for sex	.534	31.310	6.49	56.13	2.30	.016*	.263	.204
	Model 2. Adjusted for sex and age	.527	30.888	4.31	57.47	2.40	.025*	.263	.171
	Model 3. Adjusted for sex and climbing experience (years)	.725	41.636	16.17	67.10	3.38	.003*	.380	.299
	Model 4. Adjusted for sex and education level	.484	28.089	1.77	54.41	2.21	.037*	.267	.171
Hit Reaction Time (Milliseconds)	Unadjusted	.136	4.752	-9.20	18.70	.70	.490	.019	- .019
	Model 1. Adjusted for sex	.097	3.374	-13.65	20.40	.41	.687	.022	- .056
	Model 2. Adjusted for sex and age	.083	2.912	-15.31	21.14	.33	.744	.023	- .099
	Model 3. Adjusted for sex and climbing experience (years)	.299	10.024	-8.18	28.23	1.14	.266	.066	- .056
	Model 4. Adjusted for sex and education level	.128	4.561	-13.71	22.83	.52	.611	.052	- .072

Note. Data are presented as standardized regression coefficient (b), unstandardized regression coefficient (β), 95% confidence interval (95% CI), lower confidence interval (LL), upper confidence interval (UL) and P-value (*p*). * $p < .05$ indicating statistically significant associations.

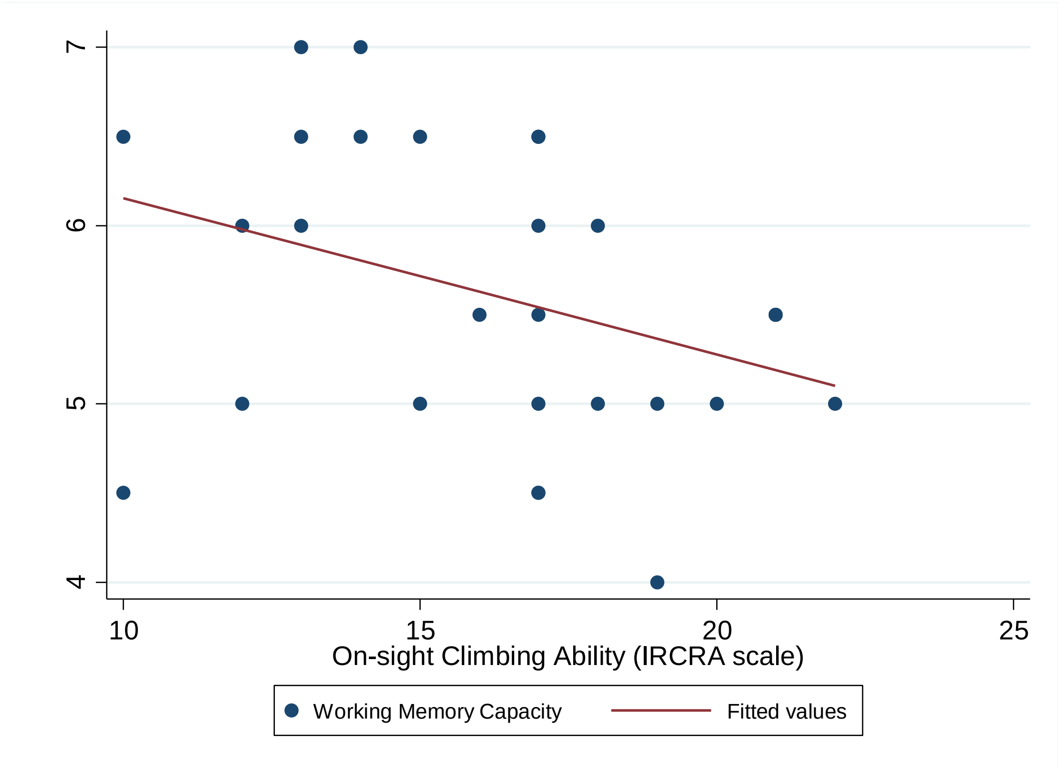

Figure 1. *Linear Relationship Between Working Memory Capacity and Climbing Ability.*

Hemodynamic responses

Correlation analyses revealed a significant positive correlation between WM load and O_2Hb in both the right and left PFC across each trial, with coefficients of r = .537 ($p <$ .001) and r = .505 ($p <$ .001), respectively. Conversely, a negative correlation was observed between WM load and HHb levels, with coefficients of r = -.500 ($p <$ .001) for the right PFC and Spearman's rho = -.595 ($p <$ .001) for the left PFC, across each trial (See **Figure 2**).

Additionally, as shown in **Table 11**, significant differences were found between Expert and Elite climbers in tHb levels at Fp1 (Mean Differences (MD) = -1.18; 95% Coefficient Interval (CI) = [-2.28, -.079]; p = .037), and HHb levels in both Fp1 (MD = -.80; 95% CI = [-1.43, -.71]; p = .015) and Fp2 (MD = - .78; 95% CI = [-1.34, - .23]; p = .008) during the WM task. Sex differences were also observed in HHb levels at Fp1 (MD = .75; 95% CI = [- .06, 1.56]; p = .025) and Fp2 (MD = 1; 95% CI = [.33, 1.67]; p = .005). **Figure 3** illustrates the changes in HHb levels in the left and right PFC for Expert vs. Elite climbers (upper panels) and Male vs. Female climbers (lower panels) after completion of the WM task. The box plots show the distribution of HHb changes, indicating differences in cerebral blood flow and de-oxygenation between the groups. A greater change in HHb levels suggests a higher PFC activity due cognitive load. Lastly, **Figure 4** illustrates an example of the changes in oxygenation and deoxygenation in the right PFC of two climbers differing in climbing ability (Expert vs. Elite) and in WM capacity. This visual comparison aims to showcase the differential patterns of activation between climbers of various skill levels under their maximum WM load.

Table 11. *Hemodynamic Changes* and Analyses of Variance in *the Prefrontal Cortex During the Working Memory Task across the Entire Sample, Categorized by Climbing Ability (Elite Vs Expert) and Sex.*

	All sample (n = 28)	**Expert** (n = 19)	**Elite** (n = 9)	**F** or χ^2	***p***	η^2	**Female** (n = 5)	**Male** (n = 23)	**F** or χ^2	***p***	η^2
Left Prefrontal Cortex (FP 1)											
△tHb (uM)	1.14 ± 1.41	.76 ± 1.44	1.94 ± 1.00*	4.85	.037	.16	.59 ± 1.58	1.26 ± 1.38	.92	.346	.03
△O_2Hb (uM)	2.48 ± 1.66	2.42 ± 1.91	2.60 ± 1.04	.07	.798	.003	1.17 ± 1.66	2.76 ± 1.55	4.21	.050	.14
△HHb (uM)	-1.20 ± .84	-1.45 ± .87	-.65 ± .39*	5.93[a]	.015	.19	-.58 ± .27	-1.33 ± .86*	5.06[a]	.025	.16
△TOI (%)	.80 ± 1.15	.89 ± 1.28	.60 ± .83	.37	.55	.01	.13 ± .70	.94 ± 1.19	2.11	.159	.08
Right Prefrontal Cortex (FP 2)											
△tHb (uM)	1.08 ±1.53	1.17 ± 1.51	0.88 ± 1.66	.22	.64	.008	.95 ± 1.06	1.11 ± 1.64	.04	.837	.002
△O_2Hb (uM)	2.43 ± 1.75	2.82 ± 1.81	1.59 ± 1.36	3.21	.082	.11	1.37 ± 1.14	2.66 ± 1.80	2.32	.140	.08
△HHb (uM)	-1.24 ± .75	-1.50 ± .72	-.71 ± .54*	8.41	.008	.24	-.42 ± .28	-1.42 ± .70*	9.49	.005	.27
△TOI (%)	.63 ± 1.44	.73 ± 1.65	.43 ± .89	.26	.612	.01	-.03 ± .93	.78 ± 1.50	1.31	.262	.05

Data presented as mean ± standard deviation.
Hemodynamic changes (△) were calculated as resulting of the difference between baseline values (two first trials) and those sampled during the last two trial of working memory task.
η^2: Effect size-partial eta squared for baseline comparisons: $\eta^2 \geq 0.01$ small effect size; $\eta^2 \geq 0.06$ medium effect size; $\eta^2 \geq 0.14$ large effect size.
**p* < 0.05 indicating significant different the from Expert climbers
[a] Kruskal wallis test
uM = 10^{-6}mol/L

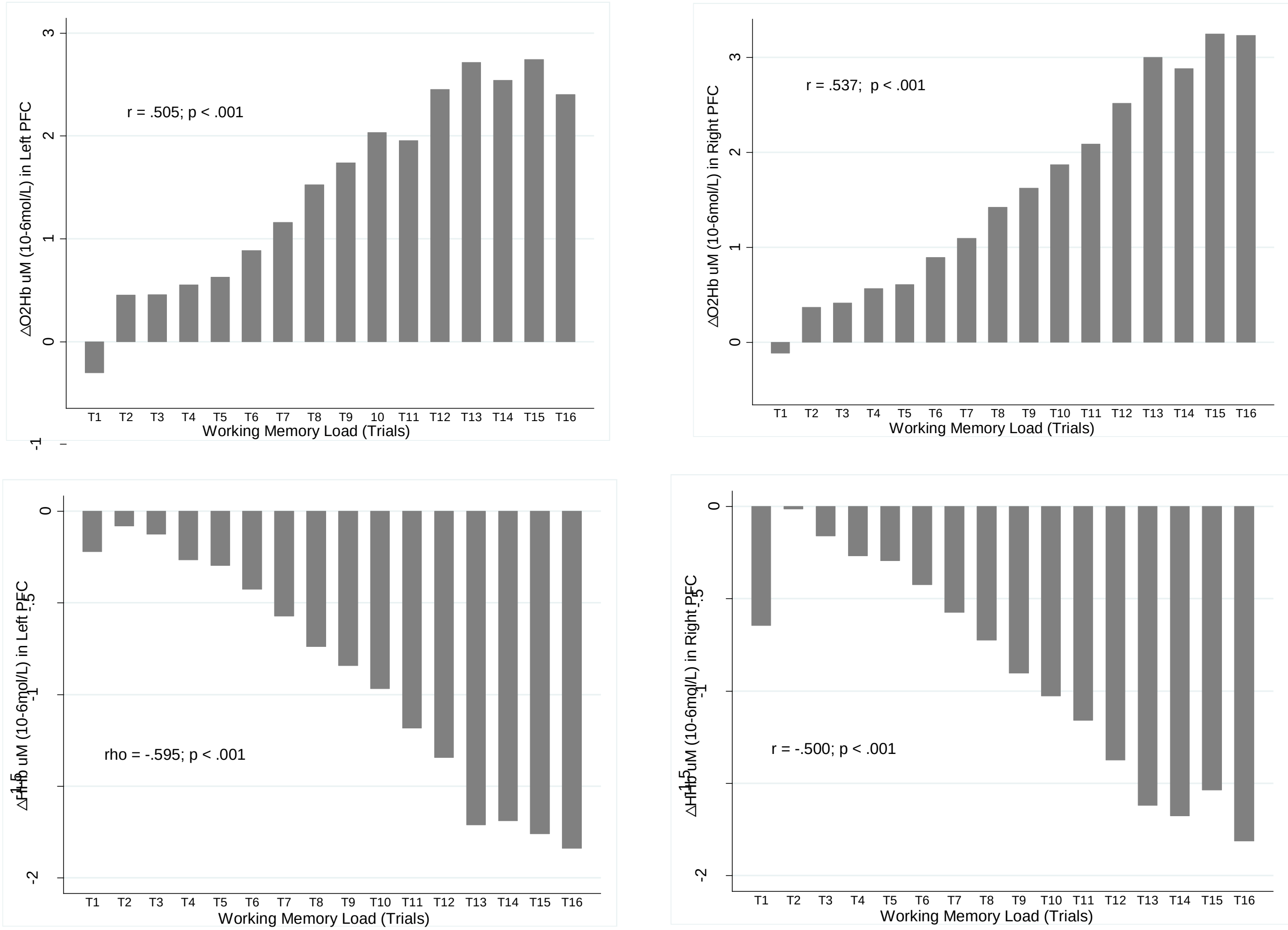

Figure 2. *Accumulated Hemodynamic Changes in Left and Right Prefrontal Cortex across Trials during the Working Memory Task in the Entire Sample of Study II.*

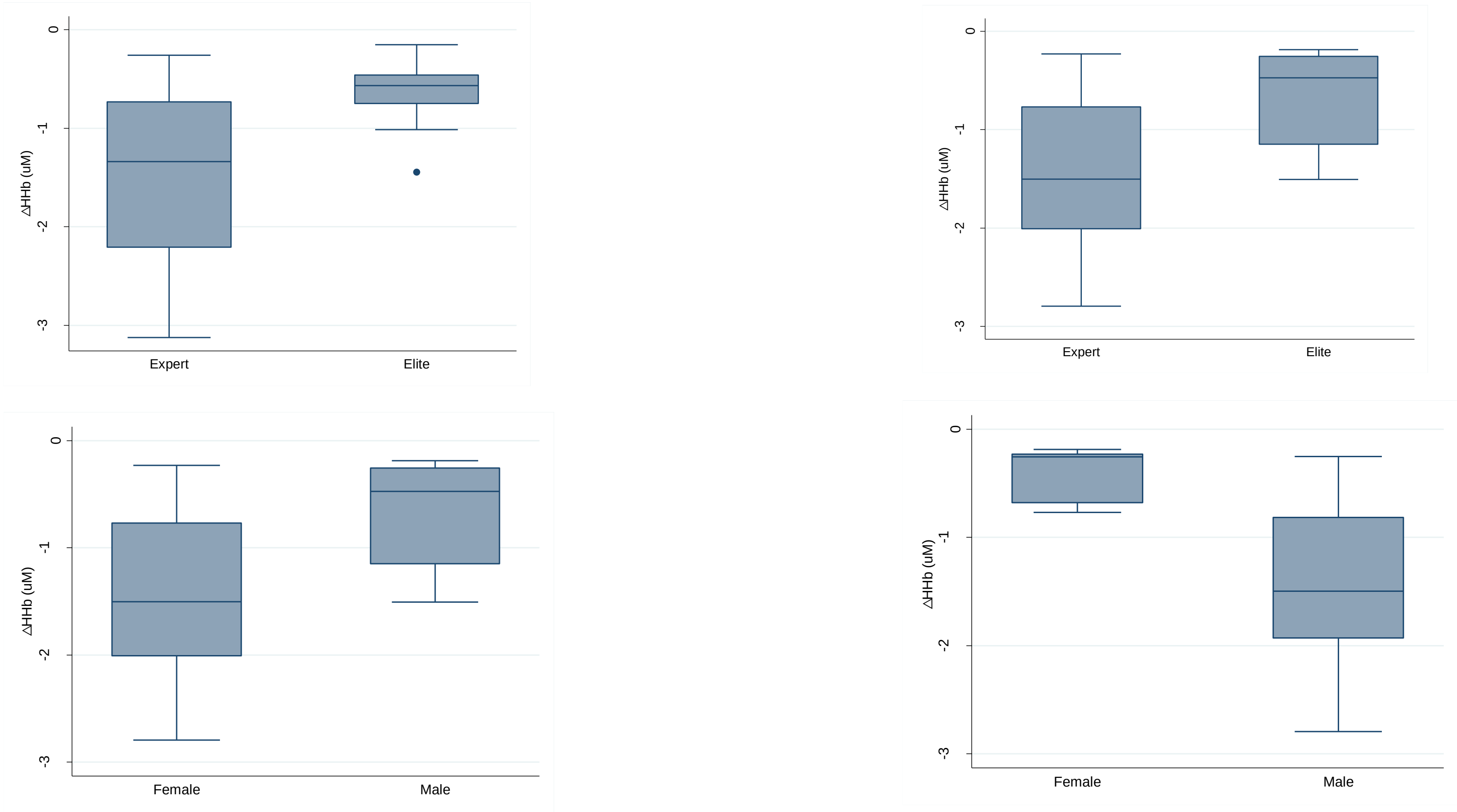

Figure 3. *De-Oxygenated Changes in Left and Right Prefrontal Cortex of Expert- Elite and Male-Female Climbers after Completing the WM Task of Study II.*

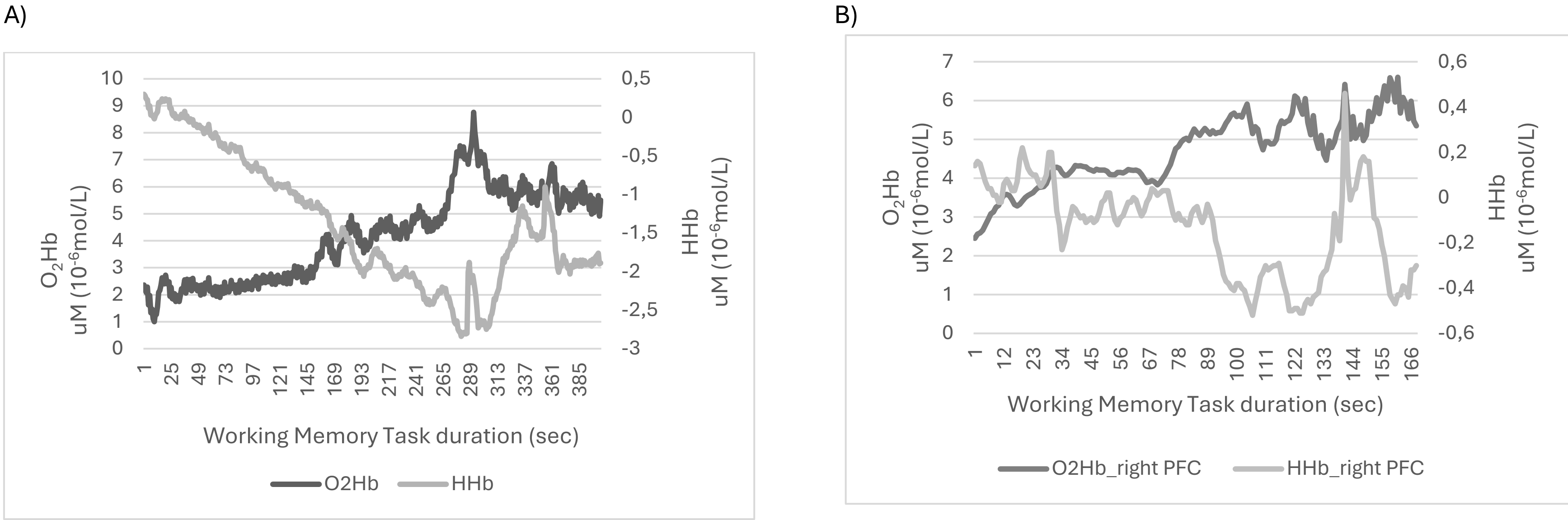

Figure 4. *An example of the Oxi- and De-Oxygenation Changes in Right Prefrontal Cortex of Male with Different Climbing Ability and Working Memory Capacity during Working Memory Task. (A) Expert Male Climber (6b+ On-Sight Climbing Ability) with 7 Span of Working Memory Capacity. (B) Elite Male Climber (7b+ On-Sight Climbing Ability) with 4 Span of Working Memory Capacity* of Study II.

III

RESULT III. Autonomous and Portable System for Training Working Memory and Climbing Technique (Invention)

Garrido-Palomino, I. & España-Romero, Vanesa (2023). Sistema autónomo y portable para el entrenamiento de la memoria de trabajo y la técnica en escalada. U202231081. Oficina Española de Patentes y Marcas (OEPM). Volumen II: Invenciones: Nº. 6512, Boletín Oficial de la Propiedad Industrial, 10 de octubre de 2023.

Autonomous and Portable System for Training Working Memory and Climbing Technique

The present invention comprises a system designed for training WM in an indoor climbing wall environment. One of its key features is its autonomy from the climbing wall itself, making it independent and portable, allowing operation in any climbing wall without the need for modifications or adaptations. The system enables the generation and recording of climbing routes by capturing data from inertial sensors attached to the climber's body as they navigate a route, and manual input via a digital tablet by the coach or user.

This invention finds application in studying the physical, technical, and psychological capacities of climbers, enabling the quantification of kinematic variables (time, speed, acceleration), as well as the development of psychological factors such as WM and climbing technique. For the measurement of kinetic variables, the invention incorporates inertial sensors located on body segments such as wrists, ankles, and waist, wirelessly connected to a personal computer whose software processes the signal and reproduces the athlete's movements on-screen. Additionally, a digital tablet equipped with specialized software allows the input of climbing routes or other relevant data for WM training. The generated routes, whether captured through inertial sensors or manually inputted via the tablet by the coach or user, must be projected onto the climbing wall for a specified duration using a laser projector or similar device. After this time elapses, the marks disappear, and it is up to the climber to replicate these marks or routes either by climbing on the wall or marking them on the computer interface.

The autonomous and portable system for training WM and technique in climbing, subject of the present invention, comprises the following components, as illustrates **Figures 5, 6 and 7**:

a) Set of inertial sensors: These sensors allow the measurement of various kinematic variables, such as the position, velocity, and acceleration of the body segment where they are located. The inertial sensors are wirelessly connected to a personal computer/data reception and acquisition system.
b) Digital tablet/computer device with a touchscreen: This device includes the necessary software to input data regarding the positioning of each hold on the climbing wall, creating a virtual image of it and the position of each grip. Moreover, and most importantly, it allows for the design of marks, images, routes, etc., facilitating the design of climbing routes or marking holds, for transmission to the personal computer/data reception and acquisition system.
c) Personal computer/Data reception and acquisition system equipped with specific software that: Receives and stores the positional data from the inertial sensors and receives and stores information about the routes generated manually on the digital tablet/computer device with a touchscreen.
d) Sound emission system: Comprising one or more speakers that emit acoustic signals or instructions to the climber. The acoustic signals can be programmed by the user to initiate WM training, indicate the start/end of tests, provide sounds for stress-inducing scenarios, or deliver instructions from the coach.
e) Laser projector: Positioned at a certain distance from the indoor climbing wall, the laser projector projects a beam of laser light onto the wall, replicating the anatomical model defined by the data captured by the inertial sensors.

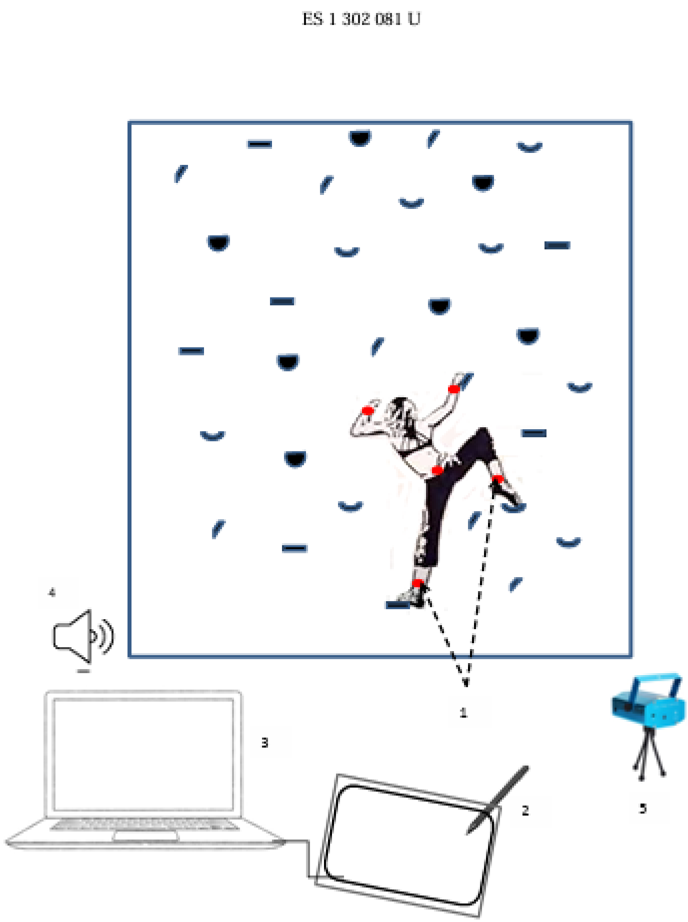

Figure 5. *An illustration of different components of the system and their location consistent on (1) Inertial sensor, (2) Digital tablet/computer device equipped with a touch screen, (3) Personal computer/Data reception and acquisition system, (4) Sound emission system, (5) Laser projector.*

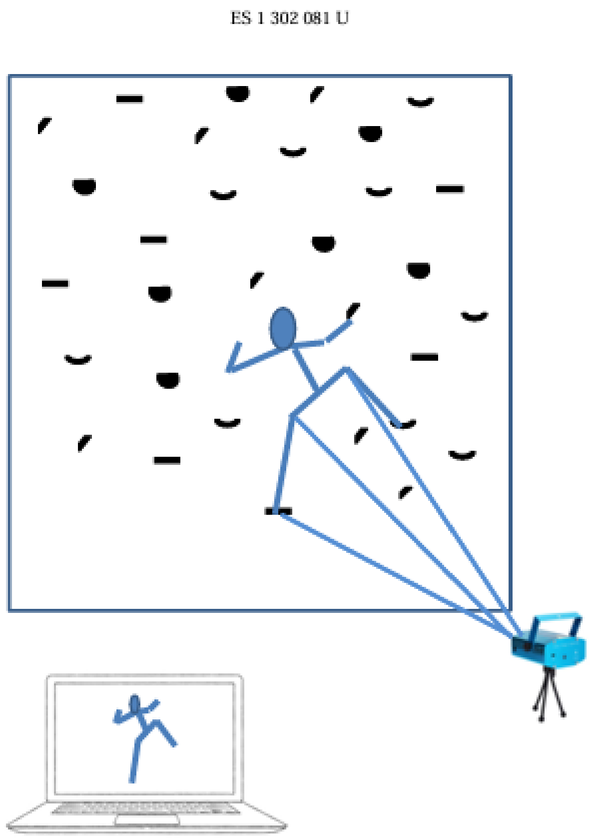

Figure 6. *A schematic projection onto the climbing wall via the laser projector of the image obtained from the inertial sensors regarding the position of each body segment of the climber.*

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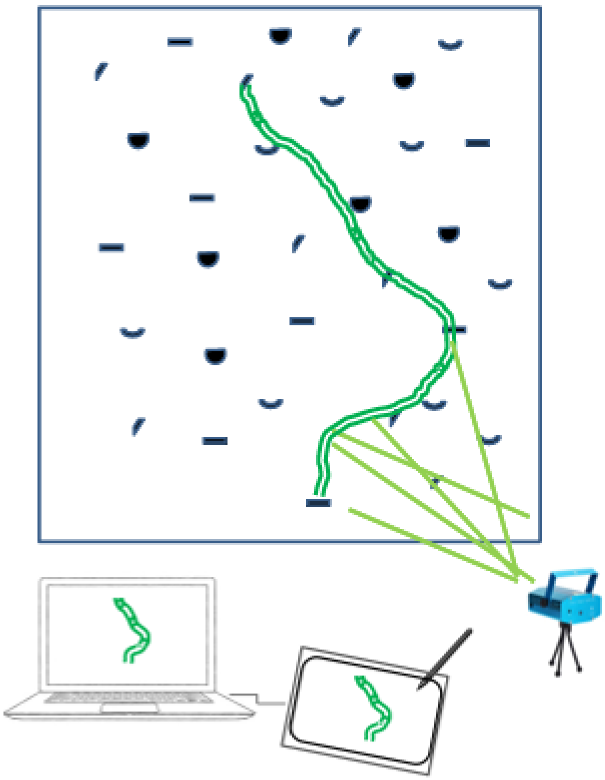

Figure 7. *Schematic projection onto the climbing wall of a route image generated through the digital tablet/computer device equipped with a touch screen, projected by the laser projector, for WM training.*

IV

RESULT IV. Role of emotional intelligence on rock climbing performance (Study III).

Garrido-Palomino, I., & España-Romero, V. (2019). Role of emotional intelligence on rock climbing performance. RICYDE: Revista Internacional de Ciencias Del Deporte, 15(57), 284–294. https://doi.org/10.5232/ricyde2019.05706

Role of emotional intelligence on rock climbing performance

The main results obtained regarding Aim 4, which aimed to explore the emotional domain by assessing EI across climbers of different skill levels, are outlined in the following sections.

Descriptive outcomes

Participants aged 18 - 44 years old, with an averaged climbing experience of 11.2 yrs. For male and 11.7 for female as shown in **Table 12**. Red-point climbing ability in women ranged from 6c to 7a in advanced climbers (n = 9), and from 7a+ to 7c in elite climbers (75th percentile, 7a+, n = 6). In men, climbing ability ranged from 6b to 7c in advanced climbers (n = 20), and from 7c+ to 8b+ in the elite group (75th percentile, 7c+, n = 8).

Table 12. Descriptive Characteristics of the Study Sample

	Male (n=28)	Female (n=14)	Expert (n=27)	Elite (n=15)
Age (yrs.)	32.8 ± 6.6	38.0 ± 3.6**	33.8 ± 6.9	35.3 ± 5.4
Weight (kg)	68.2 ± 6.5	55.2 ± 5.0**††	64.8 ± 8.9	62.2 ± 7.7
Height (cm)	173.7 ± 7.6	164.8 ± 4.7**††	171.4 ± 8.0	169.5 ± 7.8
Climbing experience (years)	11.2 ± 7.5	11.7 ± 5.9††	10.3 ± 6.2	12.8 ± 8.5††
Climbing frequency (days per week)	3.6 ± 1.3	2.8 ± 1.0	3.2 ± 1.2	3.7 ± 1.3
Onsight climbing performance (Watts scale)	2.6 ± 0.7	2.0 ± 0.5*†	2.0 ± 0.4	3.2 ± 0.5**††
Redpoint climbing performance	7a+	6c*†	6c	7c**††

** P< 0.001 and *P<0.05 differences between male and female or expert and elite climbers' group
††P<0.001 and † P<0.05 differences between male and female or expert and elite climbers adjusted by age

Main outcomes

Ability Emotional Intelligence

The scores from the MSCEIT questionnaire are presented in **Table 13**. Significant differences were found for `Facilitation Thought´, Advanced climbers had a significantly higher measure of `Facilitation Thought´ compared to Elite climbers (110.4 ± 10.6 vs. 102.9 ± 11.8, respectively). The same results were found when analyses were performed adjusted by age.

Table 13. MSCEIT Scores Split by Sex and Climbing Ability of Study III.

	Male (n=28)	Female (n=14)	Expert (n=27)	Elite (n=15)
Total score MSCEIT	103.4 ± 10.5	107.5 ± 10.4	105.1 ± 10.0	104.4 ± 11.8
Areas				
Experiential area	104.3 ± 11.0	108.5 ± 12.5	107.1 ± 11.8	103.2 ± 11.2
Strategic area	101.7 ± 11.5	104.1 ± 8.0	101.8 ± 9.9	103.9 ± 11.7
Aptitudes				
Perceiving Emotions	101.8 ± 13.5	107.6 ± 14.1	104.4 ± 15.1	102.6 ± 11.5
Facilitation Thought	107.7 ± 11.0	107.5 ± 12.7	110.4 ± 10.6	102.9 ±11.8*†
Understanding Emotions	96.9 ± 11.9	96.9 ± 7.6	95.7 ± 10.6	99.1 ± 10.7
Managing Emotions	107.5 ± 10.4	113.3 ± 11.8	110.0 ± 10.7	108.6 ± 12.3

MSCEIT scores measured by the Mayer-Salovey-Caruso Emotional Intelligence Test.
* P< 0.05 differences between male and female or expert and elite climbers
† P<0.05 differences between male and female or expert and elite climbers adjusted by age

Linear regression analyses adjusted for age revealed that `Facilitation Thought´ was inversely associated with the highest red-point ability (b: -7.04 and 95% CI: -14.19 to -0.10; $p < 0.05$). The percentage of variance (R^2) explained by self-reported grade was 14.5% (**Figure 8**).

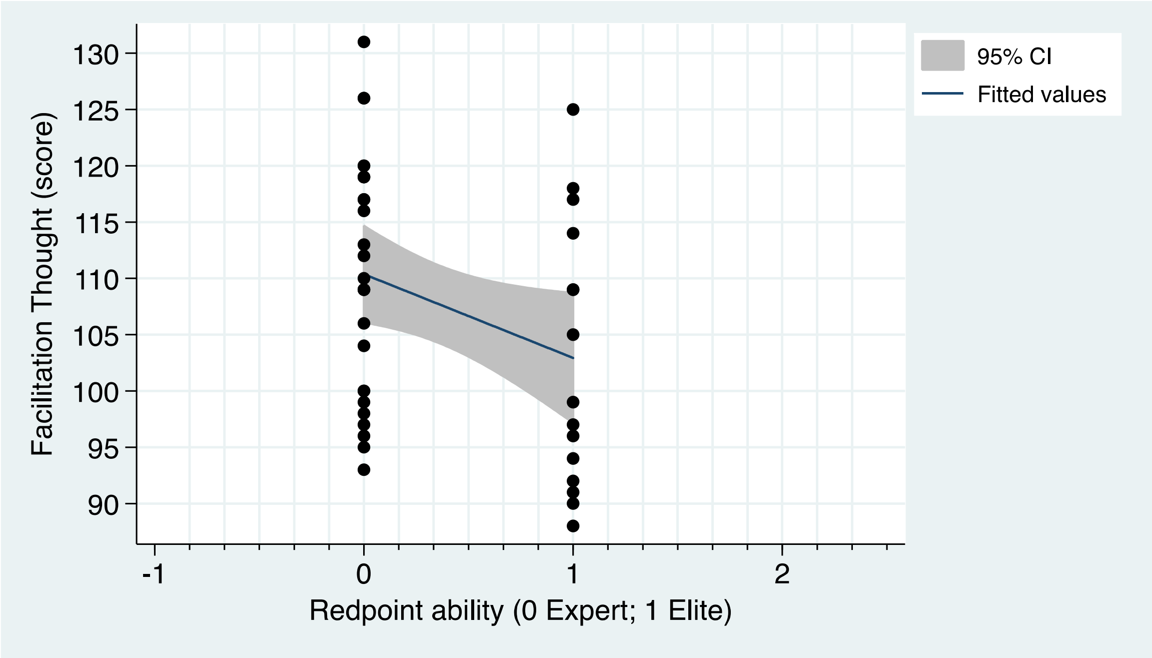

Figure 8. *Linear regression analyses between `Facilitation Thought´ and redpoint ability categories adjusted by age. (β:-8.94 and 95% CI: -17.71 to -0.16; R^2 = 0.145; p < .05) of Study III.*

Trait Emotional intelligence

The scores from the SSEIT questionnaire are presented in Table 15. Skill ‘Expression of Emotions’ and ‘Regulation of Emotions’ were significantly higher in males than females (55.6 ± 5.2 and 43.4 ± 3.5, respectively), however, the significance disappeared when adjusted for age.

Table 14. SSEIT Scores Split by Sex and Climbing Ability of Study III.

	Male (n=27)	Female (n=14)	Expert (n=26)	Elite (n=15)
Total score SSEIT	131.2 ± 10.8	126.4 ± 11.1	131.1 ± 11.2	126.7 ± 10.4
Expression of emotions	55.6 ± 5.2*	52.2 ± 4.4	55.6 ± 5.3	52.4 ± 4.4
Regulation of emotions	43.4 ± 3.5*	40.7 ± 4.2	42.8 ± 4.1	42.0 ± 3.5
Use of emotions	32.0 ± 4.3	33.4 ± 3.8	32.6 ± 3.3	32.2 ± 5.4

V

RESULT V. Fear of falling in women: A psychological training intervention improves climbing performance (Study IV).

Garrido-Palomino, I., & España-Romero, V. (2023). Fear of falling in women: A psychological training intervention improves climbing performance. Journal of Sports Sciences, 41(16), 1518–1529. https://doi.org/10.1080/02640414.2023.2281157

Fear of falling in women: A psychological training intervention improves climbing performance

Following are the main outcomes related to Aim 5, which focuses on assessing the impact of a psychological training intervention aimed at emotional regulation on anxiety levels and climbing performance in female climbers with fear of falling.

Descriptive outcomes

On-sight climbing ability ranged from uncompleted lead climbing (ranging from zero) to a level of 7a. All participants practiced outdoor climbing between 1 and 2 days per week. The psychological training intervention lasted between 65 and 193 days, with the number of sessions ranged from four to five. This variation in the number of sessions was due to differences in the causes and triggers of fear, personality characteristics, and psychological abilities. The duration of the psychological training intervention was contingent on the availability of participants to climb every weekend.

Main Outcomes

Climbing ability

The non-adjusted models repeated-measures ANOVA, as shown in **Table 15**, revealed a significant Time x Group interaction for Climbing Ability (F (2,28) = 14.23, $p < .001$, $\eta_p^2 = .50$). Further examination of post-hoc Bonferroni-corrected comparisons indicated that the main effect of the study group on the change in scores from pre-to-post intervention was found between PG vs CG in Climbing Ability ($p < .01$). In contrast, when comparing PG vs TG, a significant effect on the change in scores from pre-to-post intervention was found in Climbing Ability ($p < .05$).

Post-hoc t-tests showed a significant improvement in climbing ability in PG with a mean difference (95% confidence interval) of 5.54 (95% CI [2.10, 8.99]; ES = 1.37) and of .80 (95% CI [.14, 1.46]; ES = .57) in TG.

Anxiety and self-confidence

Repeated measured ANOVA analysis showed a significant Time x Group interaction for Cognitive Anxiety (F (2,28) = 8.63, p = .001, η_p^2 = .38), Somatic Cognitive Anxiety (F (2,28) = 8.63, p = .001, η_p^2 = .38), Somatic Anxiety (F (2,28) = 9.98, p = .005, η_p^2 = .29), and Self-Confident (F (2,28) = 26.87, p < .001, η_p^2 = .66). Further examination of post-hoc Bonferroni-corrected comparisons indicated that the main effect of the study group on the change in scores from pre-to-post intervention was found between PG vs CG in Cognitive (p < .001), and Somatic Anxiety (p < .01), and Self-Confidence (p < .001). In contrast, when comparing PG vs TG, a significant effect on the change in scores from pre-to-post intervention was found in Somatic Anxiety (p < .001), and Self- Confidence (p < .001).

Moreover, post-hoc tests for the CSAI-2 R questionnaire showed that cognitive anxiety scores also improved in both PG (−5.18; 95% CI [−7.30, −3.06]; ES = −1.85) and TG (−2.80; 95% CI [−4.84, −0.75]; ES = −1.05), while somatic anxiety scores was only improved for PG (−5.72; 95% CI [−8.09, −3.36]; ES = −1.68). Self-confidence also improved in both PG (5.00; 95% CI [3.80, 6.20]; ES = 2.86) and TG (.90; 95% CI [−.19; 1.99] (1.52); ES = .46 for TG). Finally, all evaluated CSAI-2 R parameters remained unchanged for CG (p > .05) (see **Table 15** and **Figure 9).**

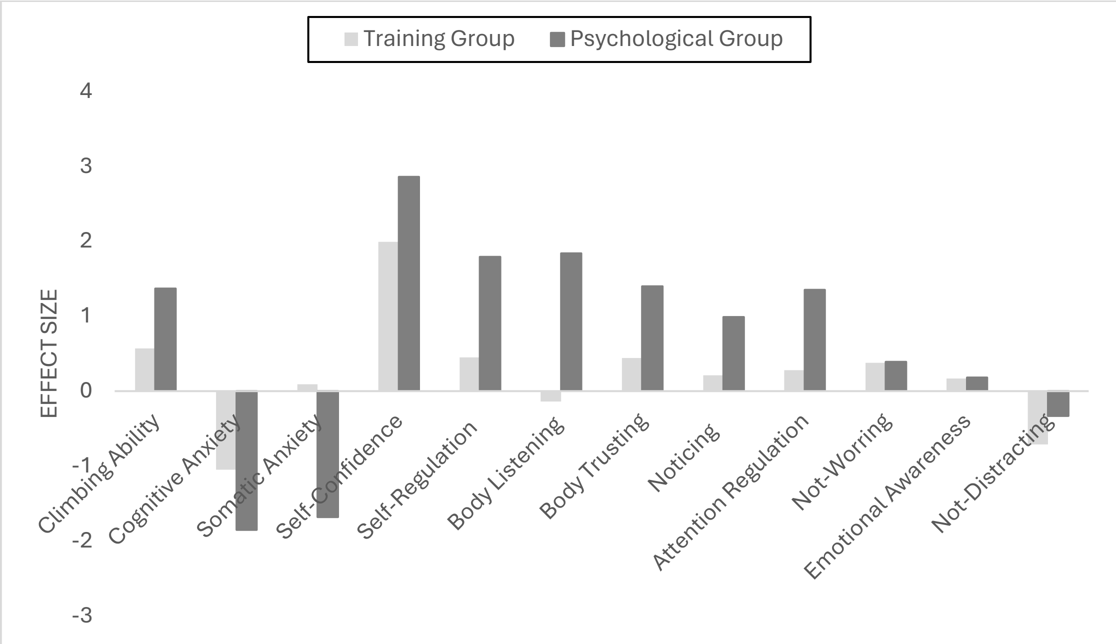

Figure 9. *Effect Size (*Cohen´s *d) for Climbing Ability, CSAI-2R and MAIA Scores in PG and TG Relative to CG after Intervention.*

Interoceptive awareness

Repeated measures ANOVA showed a significant Time x Group interaction for several IA subscales derived by the MAIA questionnaire, such as the Noticing (F (2, 28) = 3.78, $p = .035$, $\eta_p^2 = .21$); Self-Regulation (F (2, 28) = 8.43, $p = .001$, $\eta_p^2 = .37$), Body Listening (F (2, 28) = 16.99, $p < .001$, $\eta_p^2 = 0.55$) and Trusting scores (F (2, 28) = 6.93, $p < .003$, $\eta_p^2 = .33$) (see **Table 16**). A non-significant interaction was found for Not- Worrying, Not-Distracting, Emotional Awareness, and Attention Regulation subscales (F between 1.22 and 3.18; all *p* values > .05). Post-hoc Bonferroni analyses revealed significant differences for change scores from pre to post comparison between PG vs CG in Self-Regulation ($p < .001$), Body Listening ($p < .001$) and Trusting ($p < .01$). When comparing PG and TG, significant differences were found in change scores from pre- to-post for Body Listening ($p < .001$) and Trusting ($p < .05$).

Post-hoc t-tests for the MAIA questionnaire revealed changes at the PG for Noticing (.95; 95% CI [.16, 1.74]; ES = .99); Attention Regulation (.86; 95% CI [.36, 1.35]; ES = 0.99), Self-Regulation (1.29; 95% CI [0.66, 1.93]; ES = 1.79), Body Listening (1.67; 95% CI [0.97; 2.36]; ES = 1.84) and, Trusting (1.42; 95% CI [0.46; 2.38]; ES = 1.40). TG showed changes in the MAIA subscales of Attention Regulation (0.34; 95% CI [−.04; .72]; ES = .28) and Self-Regulation (.50; 95% CI [−.11; 1.11]; ES = .45). Moreover, all IA parameters measured by the MAIA questionnaire remained unchanged for the CG ($p > .05$), except for the Not-Distracting subscale, which showed a significant change ($p = .026$) (see **Table 16**).

Table 15. Descriptive Characteristics and Baseline Scores for Anxiety and Interoceptive Awareness Questionnaires Shown as Mean (Standard Deviation).

	All (n=31)	Control Group (n=10)	Training Group (n=10)	Psychological Group (n=11)	ANOVA F (2,28)	*p*	η^2	Power (%)
Age	33.23 (6.84)	33.19 (8.05)	34.03 (6.04)	32.55 (6.93)	0.12	0.891	0.01	6.60
Years Climbing	5.55 (4.21)	4.30 (2.41)	5.70 (5.91)	6.55 (3.72)	0.74	0.486	0.05	16.29
Outdoor Climbing Days per Week	1.55 (0.51)	1.43 (0.48)	1.6 (0.52)	1.73 (0.47)	2.09	0.143	0.13	39.22
Intervention Duration (Days)	119.11 (24.26)	117.17 (4.94)	116.13 (3.80)	123.58 (41.18)	0.28	0.757	0.02	9.00
Climbing Ability [a]	11.26 (4.45)	11.7 (1.77)	12.00 (2.00)	10.18 (7.14)	0.49	0.616	0.03	12.38
Anxiety measures								
Cognitive anxiety	13.80 (3.29)	13.2 (3.1)	14.1 (4.3)	14.1 (2.6)	0.24	0.790	0.02	8.57
Somatic Anxiety	15.12 (3.34)	14.5 (3.5)	15.8 (2.7)	15.1 (3.9)	0.36	0.699	0.03	10.24
Self-confidence	9.74 (2.2)	10.0 (2.4)	9.20 (1.8)	10.0 (2.4)	0.45	0.643	0.03	11.56
Interoceptive Awareness measures								
Noticing	3.11 (0.9)	3.42 (0.5)	3.32 (0.8)	2.64 (1.1)	2.74	0.082	0.16	49.70
Not-Distracting	2.67 (0.61)	2.30 (0.6)	2.73 (0.5)	2.94 (0.6)	3.39	0.048	0.19	58.99
Not-Worrying	2.14 (0.81)	2.00 (0.7)	2.40 (0.6)	2.03 (1.1)	0.74	0.485	0.05	16.31
Attention Regulation	2.64 (0.73)	2.86 (0.7)	2.53 (0.6)	2.54 (0.9)	0.62	0.543	0.04	12.59
Emotional Awareness	4.12 (0.81)	4.22 (0.8)	4.34 (0.6)	3.82 (1.0)	1.22	0.311	0.08	24.36
Self-Regulation	2.68 (0.76)	2.92 (0.7)	2.8 (0.8)	2.36 (0.8)	1.65	0.210	0.11	31.82
Body Listening	2.69 (1.06)	3.00 (0.8)	2.87 (0.7)	2.24 (1.4)	1.61	0.218	0.10	31.08
Trusting	3.10 (1.12)	3.13 (0.6)	3.17 (0.8)	3.00 (1.7)	0.06	0.940	0.004	5.79

[a] On-sight climbing ability provided according to International Rock Climbing Research Association (IRCRA) scale.

η^2: Effect size-partial eta squared for baseline comparisons: $\eta^2 \geq 0.01$ small effect size; $\eta^2 \geq 0.06$ medium effect size; $\eta^2 \geq 0.14$ large effect size.

Table 16. Mean (SD) of Self-Reported Climbing Ability, CSAI-2R and MAIA Questionnaires for Pre-Post-Test in all Groups.

	Control Group (n=10)		Training Group (n=10)		Psychological Group (n=11)		Interaction (Time x Group)			Effect Size [a]		
	Pre	Post	Pre	Post	Pre	Post	$F_{(2,28)}$	p	η_p^2	PG vs CG	PG vs TG	TG vs CG
Climbing Ability	11.7 (1.8)	10.8 (4.2)	12.0 (2.0)	12.8 (2.2) *	10.2 (7.1)	15.7 (3.5) **	14.23	<.001	.50	+++	+++	++
Anxiety measures												
Cognitive Anxiety	13.2 (3.1)	13.0 (3.2)	14.1 (4.3)	11.3 (3.6) **	14.1 (2.6)	8.9 (2.4) ***	8.63	.001	.38	+++	++	+++
Somatic Anxiety	14.5 (3.5)	14.2 (4.2)	15.8 (2.7)	15.8 (4.1)	15.1 (3.9)	9.4 (1.7) ***	9.98	.005	.29	+++	+++	-
Self-Confidence	10.0 (2.4)	10.2 (2.2)	9.2 (1.8)	10.1 (2.5) *	10.0 (2.4)	15.0 (2.1) ***	26.87	<.001	.66	+++	+++	+
Interoceptive Awareness measures												
Noticing	3.4 (0.5)	3.4 (0.5)	3.32 (0.8)	3.47 (0.6) *	2.6 (1.1)	3.6 (0.8) *	3.78	.035	.21	+++	+++	+
Not-Distracting	2.3 (0.6)	2.7 (0.4) *	2.73 (0.5)	2.5 (0.8)	2.9 (0.6)	3.1 (0.5)	1.64	.213	.10	+	+	++
Not-Worrying	2.0 (0.7)	1.8 (0.9)	2.4 (0.6)	2.57 (0.8)	2.0 (1.1)	2.6 (0.9)	1.26	.300	.08	++	+	+
Attention Regulation	2.9 (0.7)	2.0 (0.5)	2.53 (0.5)	2.87 (0.5) *	2.5 (0.9)	3.4 (0.7) **	3.18	.057	.18	+++	+++	+
Emotional Awareness	4.2 (0.8)	4.3 (0.5)	4.34 (0.6)	4.42 (0.8)	3.8 (1.0)	4.4 (0.4)	1.22	.312	.08	+++	+	-
Self-Regulation	2.9 (0.7)	2.7 (0.7)	2.80 (0.8)	3.30 (0.9) *	2.4 (0.8)	3.7 (0.7) ***	8.43	.001	.37	+++	+++	+
Body Listening	3.0 (0.8)	2.9 (6.7)	2.9 (0.7)	2.63 (0.6)	2.2 (1.4)	3.9 (0.9) ***	16.99	<.001	.55	+++	+++	-
Trusting	3.1 (0.6)	2.9 (1.0)	3.2 (0.8)	3.3 (0.8)	3.0 (1.7)	4.4 (0.7) **	6.93	.003	.33	+++	+++	+

* Significantly different from pre-and post-test: *p < .05; **p < .01; ***p < .001

[a] Effects size (Cohen´s d) for pre-post pairwise t-test comparisons: - small effect ($d \leq .20$); + moderate effect (d > .20); ++ large effect (d > .50); +++ very large effect (d > .80).

INTEGRATED DISCUSSION

INTEGRATED DISCUSSION

Previous studies have revealed that climbing requires a high level of psychological skills. Therefore, it seems logical to infer that these demanding psychological skills will be reflected in differences in cognitive and emotional abilities among climbers of different levels. Based on this reasoning, throughout the four articles and the development of the patent that comprise this Ph.D. Thesis, we aimed to enhance understanding of psychological parameters such as cognitive, emotional, and brain activity domains in climbers of various levels, from recreational to elite, specifically examining how these factors interrelate and contribute to climbing performance.

Cognitive domain in climbing

To address cognitive issue, after an exhaustive analysis of the available literature indicating that climbing appears to demand high attentional demands (Bourdin et al., 1998), our first objective was to investigate the relationship between attention, as cognitive domains, and climbing ability, while accounting for other influencing factors **(ANNEX I).** The results of the analyses showed that higher-level climbers exhibited greater accuracy in their responses during an attention task. Additionally, sex, age, experience, and cardiovascular capacity emerged as predictors of this relationship. This advantage in the attentional control of climbers, associated with their on-sight climbing level, could be explained by direct climbing practice, within the framework of the cognitive skills hypothesis, which suggests that sport can be a potential moderator in cognitive development (Singer, 2000; Voss et al., 2010). In contrast, the absence of observed differences related to redpoint climbing ability could be indicative of the higher attentional demands of the on-sight climbing style, due to the lack of prior knowledge about the route (Giles et al., 2014).

Similarly, despite literature highlighting the involvement of WM during climbing (Green & Helton, 2011), previous studies show contradictory results regarding differences in memory capacity among climbers of different levels (Heilmann, 2021; Whitaker et al., 2019). Therefore, our second objective focused on investigate the relationship between WM as cognitive domains, and climbing ability, while accounting for other influencing factors. Additionally, to strengthen our study, we examined differences in WM capacity and PFC hemodynamic responses during a WM task between different ability groups in climbing and female and male **(ANNEX II).** Surprisingly, our analyses showed that higher-level climbers had lower WM capacity compared to lower-level climbers, when considering sex, age, education level, and climbing experience. Furthermore, these results are reinforced by differences found in cerebral hemodynamics during the execution of the WM task. However, during the WM task, higher-level climbers made fewer errors, and the RT for incorrect responses or errors was longer. Overall, these results, although unexpected, are consistent with previous findings by Heilmann, (2021) and with previous literature indicating that sex (Voyer et al., 2017), age, and education level (Archer et al., 2018) moderate WM capacity. These findings could have an evolutionary explanation. A higher WM capacity, especially in lower-level climbers, may lead to greater visual attention in detecting dangerous stimuli (Wood et al., 2016). A lower WM capacity could imply more efficient cognitive functioning associated with climbing practice.

Given that the available tools only allow for the assessment of WM in a laboratory setting (Voss et al., 2010), our next objective was to design and develop an innovative tool for assessing WM in the context of climbing to bridge laboratory research with field application **(ANNEX III)**. The result was the patent of a utility model through the development of a system that allows for the illumination of sequences of holds with the same duration and sequencing as the WM task, thus enabling comparison of results with measurements in both laboratory and climbing gym settings. This tool uniquely facilitates real-time, interactive testing of climbers' WM, offering a direct assessment of cognitive processes during climbing.

Emotional domain in climbing

To address the emotional issue, we chose to explore the emotional domain by assessing EI across climbers of different skill levels **(ANNEX IV)**, given the detrimental impact of anxiety on climbing performance (Dickson et al., 2012; Draper et al., 2008, 2010; Fryer et al., 2012) and recognizing the importance of effective emotional management in addressing anxiety (Sloan et al., 2017). This analysis, which explored EI based on its two main constructs, both as trait and ability, revealed significant differences in one of the components of EI considered as an ability. Specifically, the results indicated that lower-level climbers showed a higher score in the 'Facilitation of Thought' sub-scale. 'Facilitation of Thought' refers to the ability to use emotions to enhance cognitive processing and direct attention towards relevant stimuli. This implies the capacity of emotions to facilitate judgment formation, analysis of personal and group conflicts from multiple perspectives, as well as the decision-making process (Fernández-Berrocal & Cabello, 2021). This result contributes to a deeper understanding or explanation of why lower-level climbers exhibit higher levels of anxiety compared to more advanced climbers in climbing practice. Since anxiety and fear are defensive behavioral responses that have evolved to enable an organism to avoid or reduce harm and thus ensure survival (Chen et al., 2022), this may be more prone to use their emotions to focus on the task and effectively problem-solve as a protective mechanism against potential injury. In this regard, increased anxiety could serve as a warning signal, prompting these climbers to pay sharper attention to their surroundings and take additional precautionary measures. Therefore, the higher facilitation of thought observed in less experienced climbers may be associated not only with problem-solving adapted to their skills but also with greater sensitivity to risk signals and a quicker adaptive response to mitigate potential dangers. Additionally, we found significant differences in terms of sex, concerning EI as a trait, in the sub-scales of "emotional expression" and "emotional regulation". This finding aligns with previous studies indicating that men tend to score significantly higher than women in terms of regulating their own emotions and controlling the expression of their own emotions (Sojer et al., 2023).

Finally, considering that previous literature suggests that female athletes tend to exhibit higher levels of anxiety compared to their male counterparts, and that the anxiety derived from lead climbing may affect men and women differently, we addressed our final objective. This involved evaluating the impact of a psychological training intervention focused on emotional regulation on anxiety levels and climbing performance in women climbers with fear of falling (**ANNEX V**). The main findings indicated that a psychological training intervention resulted in a significant reduction in anxiety levels, along with an improvement in climbing performance, self-confidence, and interoceptive body awareness in female climbers with fear of falling. Additionally, this improvement was significantly greater when compared to a group of women undergoing individualized physical training, as well as a control group. Taking these results into account, we can affirm that given the psychological demands of climbing, a psychological intervention in women with fear of falling leads to an improvement in climbing performance.

In summary, it is essential to interpret the results of this studies within the framework of cognition as a whole. Motor behavior involves complex reciprocal influences between cognition and emotion (Dolcos et al., 2011). During the initial stages of learning, motor behavior requires greater cognitive control (Seidler et al., 2012), which is modulated by emotions (Coombes et al., 2005). In this sense, attention is directed by emotionally relevant stimuli to protect us from dangers (Green et al., 2014; Soto et al., 2008). Visual information selected by attention is transiently stored in WM to be used or converted into a movement program (Ohbayashi et al., 2003). As individuals gain experience, the information loaded into WM depends on attentional control and its interaction with information stored in both short-term and long-term memory, which acts as a guide for selecting and loading information into WM (Cowan, 2010; Vansteenkiste et al., 2019). In conclusion, within this framework and based on the results of the studies comprising this Ph.D. Thesis, we hypothesize that in an environment where climbing involves the risk of falling, individuals with fewer skills may experience an emotional response that captures their attention due to the complexity and challenges of the environment. Therefore, novice climbers may pay closer attention to detecting "dangers" (such as the risk of falling) and would load this information into their WM to respond according to their abilities. The acquisition of physical-technical skills would be accompanied by an increase in specific environmental information stored in long-term memory, as illustrates in **Figure 10**, aiding climbers in directing their attention toward more precise cues and developing skills in emotional regulation. They would then load this information into their WM to convert it into specific movement programs. Furthermore, considering that emotions guide attention, especially towards potentially dangerous stimuli, an improvement in emotional regulation would contribute to better attentional control, a decrease in anxiety levels, and an improvement in performance.

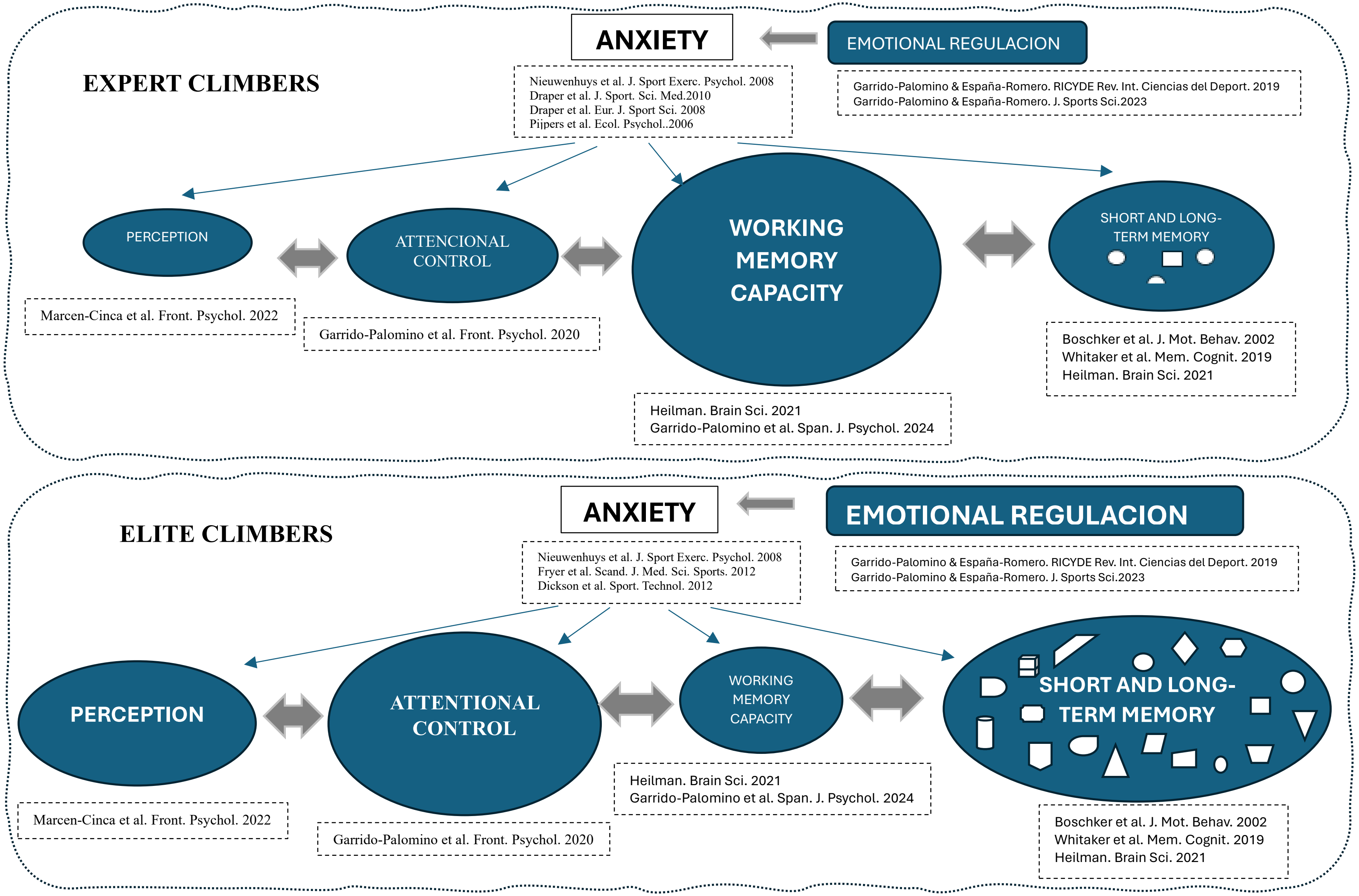

Figure 10. A schematic representation of the hypothesized cognitive functioning differences between climbers of different ability levels.

CONCLUSSIONS

CONCLUSSIONS

The present Ph.D. Thesis provides empirical evidence on cognitive and emotional differences among climbers of different skill levels. More specifically, based on the results obtained, the main conclusions are presented, detailing the corresponding publications for each of them.

1. There are differences in attentional control among climbers of different levels. Attention is positively related to on-sight climbing ability, evidenced by a higher rate of correct responses during an attention task by elite climbers compared to experts. Additionally, sex, age, education level, and climbing experience are significant predictors of this relationship (Study I).
2. There are differences in WM capacity among climbers of different skill levels, and these differences are influenced by sex, age, education level, and climbing experience. Specifically, higher-level climbers exhibit lower WM capacity compared to lower-level climbers, once sex, age, education level, and climbing experience are controlled for. Additionally, higher-level climbers show a longer RT to errors compared to lower-level climbers. Furthermore, both sex and education level significantly predict a negative relationship between error rate during the WM task and on-sight climbing ability (Study II).
3. The hemodynamic responses in the climbers' prefrontal cortex during the performance of the WM task show a consistent pattern of increased levels of oxygenated and deoxygenated hemoglobin in response to a rising WM load (Study II).
4. Expert climbers show significantly lower levels of deoxygenated hemoglobin in both the left and right prefrontal cortex as the WM load increases, compared to

elite climbers, indicating a greater cognitive effort due to the higher WM load (Study II).

5. The design and development of a tool that allows for the assessment and training of visuospatial WM in any indoor climbing wall, as well as the analysis and training of technique through the placement of inertial systems on different body areas, enables the recording of kinematic variables (Invention).
6. There are differences in ability-based EI among climbers of different levels. Specifically, expert climbers show significantly higher scores in the "Facilitation of Thought" subscale compared to elite climbers (Study III).
7. There are differences between men and women in trait-based EI. Specifically, male climbers exhibit significantly higher scores in the "Regulation of Emotions" subscale compared to female climbers (Study III).
8. A psychological training intervention reduce anxiety levels and improve climbing ability, self-confidence and interoceptive awareness in women climbers with fear of falling (Study IV).
9. Psychological training causes a stronger effect than physical training in climbing ability, anxiety, self-confidence and interoceptive awareness in women climbers with fear of falling (Study IV).

LIMITATIONS AND STRENGHS

LIMITATIONS AND STRENGHS

The studies presented in this Ph.D. Thesis are not exempt from limitations, which should be taken into consideration. Nevertheless, this Ph.D. Thesis also has several strengths that are detailed below.

Limitations

- In **Studies I**, **II** and **III** the experimental design enables us to uncover the relationships between variables, but it does not enable us to ascertain potential cause-effect relationships.
- Another limitation evident in **Studies I** and **II** is the small sample size. In **Study I**, this limitation leads to a relatively low statistical power (ranging between 64.9% to 84.8%) for the primary models, considering the number of covariates. The small sample size of **Study III** despite yielding statistically significant results, evidenced a low statistical power (53.2%). In **Study IV**, the small sample size hindered the detection of subtle between-group differences, possibly leading to Type II errors.
- In both Studies **I and II**, despite incorporating sex into the analyses, the limited number of woman participants constrains the generalizability of the results.
- Regarding the **invention**, one of the primary limitations is the lack of any studies conducted to verify the validity and reliability of the tool for measuring WM.
- The employment of questionnaires is identified as a limitation due to the low internal consistency observed in certain subscales. Specifically, in **Study III**, the low internal consistency of certain subscales of the MSCEIT questionnaire raises concerns about the reliability of measuring some aspects of EI. In **Study IV**, the very low internal consistency values of the Non-Distracting and Not-Worrying subscales of the MAIA

questionnaire should be regarded as potential indicators of unreliability in measuring IA.

- One significant limitation in **Study IV** was the lack of random assignment of participants to groups, potentially introducing selection bias. Additionally, relying solely on the absence of fear of falling in the Psychological Training Group to conclude the intervention without assessing other groups may have inflated observed effects. Also, the absence of a follow-up period prevents the long-term assessment of fear of falling control and the maintenance of changes in anxiety, climbing ability, and interoceptive awareness. Additionally, individual physical training specifics were neither controlled nor recorded in any group.

Strengths

- To our knowledge, **Study I** is the first study to measure attention in climbers quantitatively, providing a detailed evaluation of differences associated with climbing performance. Represents a novel contribution to the field by offering insights into attentional mechanisms specific to climbing.
- The **Study II** contributes to existing research by replicating and expanding upon previous findings on WM in climbing, thereby strengthening the evidence base. Moreover, explore additional measures such as error rate, RT, and hemodynamic responses in the PFC, offering a more comprehensive understanding of the WM-climbing performance relationship. Additionally, it successfully controlled for several confounding factors, enhancing internal validity and facilitating a more precise analysis of the relationship between WM capacity and climbing performance.
- To our knowledge, the **Invention** is the first tool designed to measure WM in the specific context of climbing. The design and development of this invention, uniquely

offers an opportunity to facilitate real-time, interactive testing of climbers' WM, providing a direct assessment of cognitive processes during climbing.

- The **Study III** had unique access to a highly skilled group of elite climbers and utilized two types of questionnaires to assess EI based on different theoretical models, allowing for a broader understanding of EI in climbers.
- The **Study IV** offers novel insights into the effects of an emotion-based psychological training intervention on anxiety and climbing performance in female climbers with fear of falling, presenting a unique perspective within the literature. Furthermore, the detailed description of the psychological intervention methodology enhances transparency and facilitates replication efforts. Additionally, the utilization of the Multidimensional Assessment of Interoceptive Awareness (MAIA) questionnaire provides a quantified measure of IA as part of emotional regulation, thereby enhancing the robustness of our findings. Lastly, our focus on women climbers, an underrepresented group within the climbing community, adds value to our research and may be of interest to both researchers and practitioners in the field.

FUTURE RESEARCH DIRECTIONS

FUTURE RESEARCH DIRECTIONS

Throughout the course of this Ph.D. Thesis, along with the research and reflection process aimed at the best interpretation of our data, we have identified significant differences in cognitive and emotional variables that impact climbing performance. Hence, in this section, we propose future research directions and methodological enhancements in the field of psychological climbing research to advance our understanding of climbing, such as:

- Examining whether CFR is a predictor of differences in WM between different ability groups in climbing, as well as between females and males.
- Analyzing the cerebral hemodynamic changes associated with attention among different ability groups in climbing, as well as between females and males.
- Investigating differences between climbers' levels in other critical cognitive functions such as response inhibition or problem-solving.
- Exploring potential relationships or interactions between emotion and other cognitive variables that may impact climbing performance, such as attentional resources, WM, response inhibition, or problem-solving abilities.
- Employing experimental designs focused on verifying whether climbers with better attention are less affected by anxiety.
- Examining the potential differences in attention and WM resulting from climbing training between climbers and non-climbers.
- Studying the reliability and validity of the developed tool for measuring WM in specific contexts (Autonomous and Portable System for Training Working Memory and Climbing Technique).

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ANNEXES

ANNEXES

ANNEX I. ATTENTIONAL DIFFERENCES AS A FUNCTION OF ROCK CLIMBING PERFORMANCE

frontiers in Psychology

ORIGINAL RESEARCH
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Attentional Differences as a Function of Rock Climbing Performance

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The purpose of this study was to investigate the relationship between attention (using two different attention tasks) and self-reported climbing ability while considering potential confounding factors (sex, age, climbing experience, and cardiorespiratory fitness) in a group of experienced climbers. Accuracy of response (AC) and reaction time (RT) from two different attention tasks using the Vienna Test System, along with self-reported on-sight and red-point climbing ability, were assessed in 35 climbers. Linear regression revealed that climbers with the highest self-reported on-sight grade had better AC during the attention task. Linear regression models revealed, after controlling for potential confounders, that AC, measured using two attention tasks, was positively related to climbers' highest self-reported on-sight climbing ability ($\beta = 0.388$; $p = 0.031$). No significant differences were found between AC and self-reported red-point climbing ability ($\beta = 0.286$; $p = 0.064$). No significant relationship was found between RT and climbing ability ($\beta = -0.102$ to 0.020; $p = 0.064$). In conclusion, higher-level rock climbers appear to have an enhanced attention, which is related to on-sight lead climbing style, and thus, it may be an important component of climbing performance. Coaches should consider incorporating techniques to train attention based on on-sight climbing style in climbers.

Keywords: attention, climbing ability, physical condition, performance, on sight, red point, selective attention

INTRODUCTION

Attention is a central feature of all perceptual and cognitive functioning (Chun et al., 2011), which allows for the selection and processing of information (Kahneman, 1973; Lavie, 2005). Attention is composed of three distinct networks which are responsible for controlling different attentional functions; they are orienting, alerting, and executive control (Posner, 2017). Orienting is primarily responsible for the ability to prioritize sensory input by selecting a modality. Alerting serves to produce and maintain optimal levels of arousal and performance, a necessary prerequisite for other attention functions (Peterson and Posner, 2012). Finally, executive control is responsible for directing attention to relevant and useful information, away from irrelevant information, and also for inhibiting extraneous stimuli (Roderer et al., 2012). Collectively, these systems can be overloaded when individuals attempt to multitask and divide their attentional capacity between selecting information and deciding on action strategies. Consequently, it is unsurprising that in sports, attention appears to be related to sport practice (Kioumourtzoglou et al., 1998;

Williams and Davids, 1998; Heppe et al., 2016; Sanchez-Lopez et al., 2016; Qiu et al., 2018; Meng et al., 2019). This has been shown to be the case in sports such as martial arts (Sanchez-Lopez et al., 2016), basketball (Qiu et al., 2018), soccer (Heppe et al., 2016), and volleyball (Kioumourtzoglou et al., 1998). However, the differences in attention responses seem to depend on the influence of a variety of information processing demands associated with each sport's modality (Singer, 2000; Voss et al., 2010).

Specifically, in climbing, several authors have studied attention and climbing performance (Bourdin et al., 1998; Nieuwenhuys et al., 2008; Green and Helton, 2011; Young, 2011; Green et al., 2014). It has been suggested that climbing performance could be associated with attentional control (Young, 2011), which is associated with postural control and climbing route difficulty (Bourdin et al., 1998). Young (2011) demonstrated that while ascending, climbers who were distracted (via cognitive interference) by a task that necessitated a heightened degree of attention performed significantly worse (i.e., in terms of increased climbing time) than non-distracted climbers. Similarly, the effect of attentional interference on climbing performance was demonstrated by Green and Helton (2011). The authors suggested that when climbers use their attentional resources in a task other than climbing (i.e., a memory task), climbing efficiency and distance ascended decreased. It has also been shown that attentional demands increase with the difficulty of a climbing task, which further affects climbing efficiency (Bourdin et al., 1998). Despite the literature describing the influence of attention on different aspects of climbing performance, to date, data investigating the relationship between attention and climbing performance remain limited. Given the psychophysiological demands of rock climbing ability (Giles et al., 2014) which encompass physical and tactical elements combined with complex psychological traits such as a high self-confidence and low trait anxiety (Aras and Ewert, 2016), this lack of research seems unusual.

As rock climbing ability has previously been associated with a high cardiorespiratory fitness (CRF) (Aras and Ewert, 2016) and this is known to be related to attention (Colcombe and Kramer, 2003; Kramer and Colcombe, 2018), it may be that CRF also has some influence on climbers' attentional performance. Greater CRF appears to be associated with a better cognitive function, which is related to an increased ability of the heart to deliver oxygenated blood to cerebral structures (Colcombe and Kramer, 2003), cerebral blood flow (Brown et al., 2010), and a brain-derived neurotrophic factor (Vaynman et al., 2003). Luque-Casado et al. (2016) suggested that there is likely to be a relationship between CRF and sustained attention in sports performance. Those authors observed that cyclists and triathletes with higher CRF had shorter reaction times (RTs) than those with a lower CRF during a sustained attention task. Further, it has also been proposed that nonathletes with a high CRF may have a better ability to allocate attentional resources over time compared to nonathletes with a low CRF during a sustained attention task (Ciria et al., 2017). Further, Sanabria et al. (2019) speculated that the relationship between CRF and sustained attention may be dependent on the type of sport being conducted. Given that rock climbing has been shown to independently have both a high CRF (Fryer et al., 2017) and a high attention demand (Bourdin et al., 1998; Green and Helton, 2011), CRF may be a physiological mediator that could at least in part explain on-sight and red-point ability. To our knowledge, the relationship between ability level (on-sight and red-point), CRF, and attention in rock climbers has not yet been studied. Therefore, the main purpose of the present study was to investigate the relationship between attention (using two different attention tasks) and self-reported climbing ability, taking into account potential confounding factors (sex, age, climbing experience, and CRF) in a group of experienced climbers.

MATERIALS AND METHODS

Participants

Thirty-five sports climbers (10 women), mean age 34.7 ± 6.2 years, volunteered to take part in the study. All participants were healthy, were nonsmokers, and were not taking any vascular acting medication. Participants were asked not to consume food for 4 h prior to testing and to avoid caffeine and exercise for a minimum of 12 h. All testing sessions were conducted in the same week, in an environmentally controlled exercise laboratory. Participants read and signed the informed consent prior to participation in the study. The study protocol was approved by the Institutional Review Committee for Research Involving Human Subjects prior to recruitment; data collection was performed in accordance with the ethical standards set by the journal and the Declaration of Helsinki. Data from this study come from the High-Performance International Rock-Climbing Research Group (C-HIPPER).

Procedure, Apparatus, and Materials

Participants visited the laboratory once. During the visit, each participant completed forms for the determination of informed consent, health history, and demographic data. Detailed information on climbing experience (years), frequency (days per week), and self-reported rock climbing ability were recorded. Two attention tasks (Signal Detection and Determination Tasks) were administered (counterbalanced) with a 30-min break between each, using a laptop (15 in., 1,366 × 768 color screen) running the Vienna Test System software version 26.04 (Schuhfried, Austria). In addition, participants completed an incremental treadmill cardiorespiratory exercise test to determine CRF.

Self-Reported Climbing Ability

Rock climbing ability is most commonly expressed in terms of the best ascent of a route within the last 6–12 months. Routes are ascended as either on-sight (no prior knowledge or visual route inspection requiring a screening to find new holds) or red-point (pre-practiced where the athlete remembers the location of each hold and the movement required). Climbing ability was reported as the best grade achieved 6 months prior to the study. Self-report has been used for on-sight and red-point performance extensively within the literature (Baláš et al., 2017;

Fryer et al., 2017; Zarattini et al., 2018). It has been shown to be a valid assessment of on-sight ability level (Draper et al., 2011a). Climbers had a best 6-month on-sight ability ranging from 6a+ to 8a+ and from 6b to 8b+ for the best 6-month red-point ability based on the French grading system. In brief, this system is based on a scale of integers ranging from 4 (very easy) upward to 9 (very difficult) with letter subdivisions of a, a+, b, b+, c, and c+ from 6a to upward. In accordance with the Position Statement by the International Rock Climbing Research Association (IRCRA; Draper et al., 2016), performance grades were converted from French Sport to specific numerical values (IRCRA grades) to enable calculations and statistical analyses. The IRCRA scale ranges between 1 (very easy) and 32 (very difficult), for reporting climber ability (Draper et al., 2011a, 2016). Climbers had a best 6-month on-sight ability ranging from 12 to 24 and red-point from 13 to 26 based on the IRCRA scale (see **Table 1**).

Attention Tasks

Signal Detection Task

The Signal Detection Task (SIGNAL, 26.04 versions, Vienna Test System) was used to evaluate the accuracy of participants' response (AC) to a visual scanning and selective attention (Chong and Ong, 2015). This task was characterized by the presentation of an infrequent and unexpected target among frequent nontarget stimuli (distractors) for a relatively long period of time, requiring participants to be precise in order to detect the objective stimulus between the distractors. Specifically, during the SIGNAL task, white dots pseudorandomly disappear and appear on a black background. Participants were instructed to press the indicated key with the index finger of their dominant hand each time they detected a programmed stimulus constellation, created by four points that formed a square (see **Figure 1** for an illustration of technical terms). Climbers used headphones while performing the tasks to reduce distraction because of background noise.

The SIGNAL task had a total duration of 840 s (including the instruction and practice phases). The main practice phase had 1,000 point changes with a total of 60 stimulus constellations, this task being only trial. The number of correct responses on time as a measure of AC in the execution of the task was collected in the percentage for the final analysis.

TABLE 1 | Mean (SD) of the anthropometric, demographic, physical fitness, and performance data in the care tasks of the participants of this study.

	All (n = 35)	Male (n = 25)	Female (n = 10)
Age (years)	34.7 (6.2)	33.5 (6.5)	37.9 (4.2)*
Mass (kg)	64.5 (8.6)	68.3 (6.7)	55.2 (5)+
Height (cm)	171.5 (8.0)	173.7 (8.0)	166 (4.9)+
Experience (years)	11.1 (7.0)	11.5 (7.6)	10.1 (5.7)
Self-reported climbing ability			
Best 6-month on-sight grade (French)	7a (3.0)	7a+ (2.9)	6b+ (1.6)*
Best 6-month red-point grade (French)	7a+ (3.6)	7b (3.7)	6c+ (1.6)*
Treadmill measures			
Cardiorespiratory fitness ($ml \cdot kg \cdot min^{-1}$)	48.6 (5.3)	50.7 (4.9)	45.1 (4.6)*
Heart rate (bpm)	186.4 (10.5)	188.0 (10.9)	182.6 (8.9)

*$p < 0.05$; +$p < 0.001$.

Determination Task

A modified version of the S12 Determination Task (DT, 32.00 version, Vienna Test Systems) was used to measure the speed of motor response, also called RT (Chong and Ong, 2015). This task was characterized by different temporal uncertainties of stimulus presentations. Specifically, the DT displayed 10 black-bordered white squares on a white background, arrayed in two horizontal rows of five. Each trial consisted of a square being temporarily filled with one of five different colors, namely, black, blue, green, yellow, or red, which appeared in one of 10 different locations (five in an upper row and five in a lower row). Participants were required to quickly press the corresponding colored button, using the dominant hand, to score a correct answer (see **Figure 2** for an illustration of appearance terms).

Regardless of the speed of participant response, the colored square would remain constant for 1,250 ms before being superseded by the next trial, with a different random square now colored and another participant response required. The DT had a total duration of 950 s (including the familiarization and instruction phases). Familiarization phases were 300 s long and consisted of 20 stimuli. The instruction phase with a duration of 650 s consisted of three different trials with a total of 540 stimuli (79 white, 74 yellow, 78 red, 78 green, and 74 blue). Each trial had 180 stimuli with durations of 1,582, 948, and 1,078 ms for the first, second, and third trials, respectively. The same random sequence of stimulus presentation was used for all participants. Speed response as a measure of RT in the execution of the task (ms) was collected from each condition for final data analysis.

Cardiorespiratory Fitness

Cardiorespiratory fitness was assessed by an incremental treadmill cardiorespiratory exercise test using the athlete-led protocol (Draper and Marshall, 2014). Oxygen uptake was measured using a portable breath-by-breath expired air analyzer ($K4b^2$Cosmed, Rome, Italy) weighing 1.5 kg. Data were transferred continuously via telemetry to a portable laptop. Breath-by-breath data were recorded continuously before, during, and after 5 min of running. Breath-by-breath data were averaged over 10-s intervals and exported to Excel and STATA for final data analysis. Heart rate and time to exhaustion were also collected.

Statistical Analyses

All data were found to be normally distributed by Shapiro–Wilk and had equal variances. Participant characteristics are presented as mean and standard deviation (SD) for continuous variables and frequencies for categorical variables. Potential sex differences for each dependent variable were analyzed by t-test for continuous variables and chi-square tests for categorical variables. Pearson correlations were used to examine the relationship between attention tasks and descriptive climbing parameters. The Mallow Cp (Mallows, 1973) statistic regression model was used to find the optimum descriptive variables for the forecasting of attention tasks and climbing ability. Linear

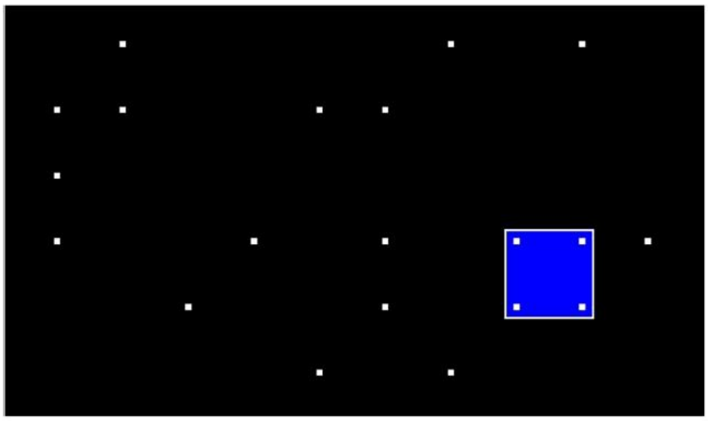

FIGURE 1 | Signal detection task from vienna test system.

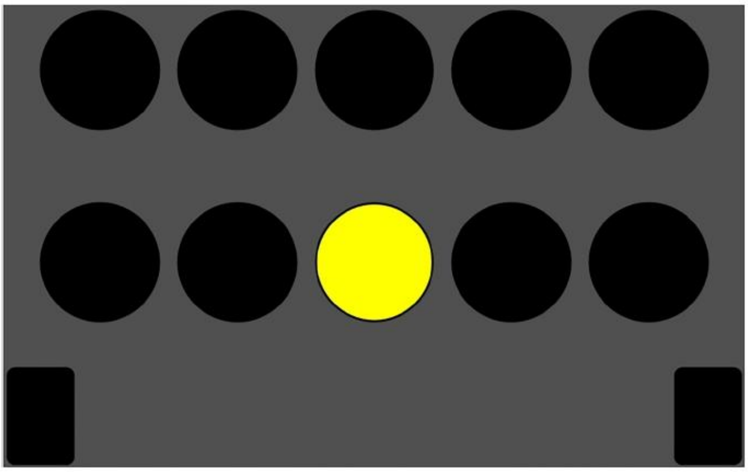

FIGURE 2 | Detection task (modified version) from vienna test system.

regression was performed to examine the association between climbing ability (on-sight or red-point) and attention task (AC or RT). In addition to the performance, covariates were included in the regression analyses. Specifically, three levels of adjustment were used: Model 1, unadjusted; Model 2, adjusted for sex, age, and climbing experience (years climbing); and Model 3, adjusted for sex, age, climbing experience (years climbing), and CRF (Cp Mallow: 3.38). Collinearity among the exposures was checked, and multicollinearity was not found in any of the models used. For all, the variance inflation factor was below 10, and the averaged variance inflation factor was close to 1 (Myers, 1990). It is important to highlight that two of the participants (both male) were excluded from just the RT (not AC) analyses because they were color blind. Statistical analyses were performed using STATA version 14.0 (Stata Corp, College Station, TX, United States). Statistical significance was set at $p < 0.05$.

RESULTS

Participant characteristics are shown in **Table 1**. Males were younger, heavier, and taller than females ($p < 0.05$). Moreover, males had a higher on-sight and red-point climbing ability with a greater CRF compared to females ($p < 0.001$ in all cases). Mean climbing experience was similar in both sexes.

Mean AC and RT measures in the attention tasks for all participants are presented in **Table 2**. No significant differences were found between male and female participants for any attention tasks, i.e., SIGNAL and DT.

The relationship between AC and self-reported on-sight climbing ability is shown in **Table 3**. Full linear regression model analysis revealed that AC (measured by SIGNAL detection task), was positively related with the highest self-reported on-sight ability (β = 0.388; p = 0.031). However, there was no significant relationship between AC and self-reported red-point ability (β = 0.286; p = 0.064) (see **Table 4**).

The relationship between RT and self-reported on-sight and red-point ability is presented in **Tables 5, 6**. Linear regression analysis revealed that there were no significant relationships between RT and self-reported on-sight (β = −0.102 to 0.020; p = 0.304 to 0.680) or red-point ability (β = −0.089 to 0.007; p = 0.306 to 0.893).

DISCUSSION

The current study is the first to assess the relationship between attention and self-reported climbing ability (on-sight and red-point) in rock climbers. Further, it is the first to assess how potential confounding factors may affect the predictive attention functioning. The results suggested that attention is significantly related to on-sight but not red-point climbing ability.

Greater levels of attention in higher-ability climbers suggest two possibilities. First, there is a degree of self-selection, with the higher-ability climbers' performance occurring because of naturally greater levels of attention. Second, and more likely, is that higher-ability climbers develop better attention, through repeated practice of the climbing task that requires them to detect the hand and footholds when they climb on-sight, as suggested by the "cognitive abilities hypothesis." This hypothesis focuses on the direct relationship between sport practice and the cognitive abilities which could be associated with the interaction between the athlete and their specialized environment (Singer, 2000; Mann et al., 2007). The hypothesis suggests that if volitional and repeated practice is the driving force behind mechanisms of brain plasticity (Debarnot et al., 2014), then sport type may be

TABLE 2 | Mean (SD) attention tasks [accuracy of response (AC) and reaction time (RT)] for all participants and by sex.

	All (n = 35)	Male (n = 25)	Female (n = 10)
Accuracy of response (%)	87.6(6.1)	88.8(5.7)	84.8(6.1)
Reaction time (ms)[a]			
Trial 1	673.03 (50.59)	669.13 (56.4)	682 (34.58)
Trial 2	657.88 (48.07)	650.87 (49.99)	674 (41.15)
Trial 3	665.15 (46.65)	660 (46.71)	677 (46.68)
Total	665.8 (43.6)	660 (46.8)	679 (33.5)

[a]*Two daltonic participant were excluded from reaction time analyses, n = 33 (23 males).*

TABLE 3 | Relationship between accuracy of response (AC; dependent variable) and self-reported on-sight climbing ability (independent variable) in 35 experienced climbers.

	β	p	R^2	R^2 adj
Model 1	0.371	***0.028***	0.134	0.112
Model 2	0.278	*0.161*	0.191	0.083
Model 3	0.388	***0.031***	0.343	0.225

Model 1: unadjusted; Model 2: sex, age, and climbing experience (years); Model 3: sex, age, climbing experience (years), and $\dot{V}O_{2max}$. β, beta, regression equation; LCI, lower confidence interval (95%); UCI, upper confidence interval (95%).

TABLE 4 | Relationship between accuracy of response (AC, dependent variable) and self-reported red-point climbing ability (independent variable) in 35 experienced climbers.

	β	p	R^2	R^2 adj
Model 1	0.308	*0.072*	0.095	0.067
Model 2	0.170	*0.182*	0.160	0.047
Model 3	0.286	*0.064*	0.298	0.172

Model 1: unadjusted; Model 2: sex, age, and climbing experience (years); Model 3: sex, age, climbing experience (years), and $\dot{V}O_{2max}$. β, beta, regression equation.

TABLE 5 | Relationship between reaction time (RT; dependent variable) and self-reported on-sight climbing ability (independent variable) in 33 experienced climbers.

RT	β	p	R^2	R^2 adj
Model 1				
Trial 1	−0.086	*0.632*	0.008	−0.025
Trial 2	−0.075	*0.680*	0.006	−0.027
Trial 3	−0.102	*0.570*	0.011	−0.021
Model 2				
Trial 1	−0.033	*0.304*	0.154	0.033
Trial 2	0.015	*0.388*	0.133	0.009
Trial 3	−0.033	*0.519*	0.106	−0.022
Model 3				
Trial 1	−0.029	*0.442*	0.155	−0.002
Trial 2	0.020	*0.535*	0.134	−0.026
Trial 3	−0.024	*0.645*	0.111	−0.053

Model 1: unadjusted; Model 2: sex, age, and climbing experience (years); Model 3: age, climbing experience (years), and VO_{2max}; β, beta, regression equation; RT: reaction time.

TABLE 6 | Relationship between reaction time (RT; dependent variable) and self-reported red-point climbing ability (independent variable) in 33 experienced climbers.

	β	p	R^2	R^2 adj
Model 1				
Trial 1	−0.024	*0.893*	0.001	−0.032
Trial 2	−0.051	*0.780*	0.003	−0.030
Trial 3	−0.089	*0.621*	0.008	−0.024
Model 2				
Trial 1	−0.017	*0.306*	0.153	0.032
Trial 2	0.007	*0.389*	0.133	0.009
Trial 3	−0.066	*0.506*	0.108	−0.019
Model 3				
Trial 1	−0.010	*0.444*	0.155	−0.003
Trial 2	0.014	*0.536*	0.134	−0.026
Trial 3	−0.052	*0.637*	*0.113*	−0.051

Model 1: unadjusted; Model 2: sex, age, and climbing experience (years); Model 3: sex, age, climbing experience (years), and VO_{2max}; β, beta, regression equation.

also a potential moderator of the sport–cognition relationship (Fetz, 2007; Voss et al., 2010). As such, different sports appear to have different influences on cognitive functioning. For instance, Lum et al. (2002) observed that athletes from externally paced sports (i.e., soccer) were better at voluntarily orienting attention to locations where useful information was, whereas athletes from self-paced sports (i.e., swimming) and/or nonathletes were not as good at voluntary orienting attention. This may in part explain why dynamic sports place a high premium on voluntary allocation of spatial attention. Kioumourtzoglou et al. (1998) analyzed perceptual speed, prediction, selective attention, decision making, focused attention, estimation of speed and direction of a moving object, visual RT, and spatial orientation between experts and novice basketball, volleyball, and water polo players. The authors found that expert basketball players had better selective attention compared to novices. In addition, expert volleyball players had better focused attention, prediction, and estimation of speed and direction of a moving object compared to novices. Lastly, water polo players had significantly better decision making, visual RT, and spatial orientation than novices. As such, in the current study, the "cognitive abilities hypothesis" may in part explain why a better attention in higher-level climbers could be associated with the characteristics of a difficult route (i.e., small holds are more difficult to find).

Analyses, shown in **Tables 5**, **6**, revealed that there was no relationship between RT and either on-sight or red-point ability. The absence of a relationship between RT and ability, together with the differences found in AC, is consistent with the findings of Wang et al. (2013). Here, the authors suggest that differences in the execution of tasks and attention may be found depending on the nature of the sport, i.e., whether it is self-paced or externally paced. The absence of differences in RT measures between ability groups could indicate the type of perceptual–cognitive abilities required when climbing. The self-paced nature of climbing means that the athletes' performance is less influenced by temporal pressure and more by the AC. However, it is also possible that an expert performance would be characterized by a more strategic and adapted allocation of the attentional resources (Bourdin et al., 1998). Future research should investigate this using a sample encompassing athletes with a range of different abilities from a variety of sports. This would help to clarify the potential differences between ability levels and types of sport (self-paced vs. externally paced).

Previous research investigating the relationship between fitness and performance in attention tasks (Luque-Casado et al., 2016; Ciria et al., 2017) suggested that CRF was an important mediator. However, our results do not support such a relationship. This divergent finding may be because previous research used different attention tasks and has compared sedentary participants with trained athletes, whereas the present study used only trained athletes albeit with different ability levels. In addition, the importance of CRF and attention has been investigated in sports where CRF is the primary factor for performance, such as triathlon and cycling. However, our data provide evidence in favor of the "hypothesis of cognitive abilities" associated with the interaction between the athlete and their specialized environment (Singer, 2000).

Climbing is a sport that demands attention to progress along the path without falls or failures and without attending to factors external to the task (e.g., risk to fall) which could affect performance. These performance advantages in AC on the attention task could explain why better climbers are less affected by anxiety when on-sight climbing, as previously reported by Draper et al. (2011b), particularly given that anxiety results in part from the failure of the attention network (Ghassemzadeh et al., 2019). As such, the stronger relationship between attention and on-sight climbing ability could also be explained by the absence of anxiety seen in advanced climbers (Fryer et al., 2013), and thus, they may have an enhanced ability to focus on the physical movements. One possible explanation for this difference in the AC in the attention task could be the general training of climbers, since during climbing, long periods of attention (i.e., monitoring) are required for good performance (Bourdin et al., 1998). As suggested by Pijpers et al. (2006), emotional state (anxiety) affects the attentional control and realization of affordances, but the inverse may be also possible. In this sense, we hypothesized that climbers with better attention would be less affected by the negative effect of anxiety, by focusing only on the relevant aspects of a climbing task such as the hold type or foot placement.

The current study did not reveal any relationships between attention and red-point climbing ability. This finding is likely explained by the different characteristics between red-point and on-sight types of climbing. While on-sight climbing requires visual inspection of the route to look for the best/next hold to keep ascending, a red-point ascent is defined by a climber's previous knowledge of the route, its holds, and the movement sequences required; thus, the attentional demands of the red-point style are likely lower. The current study supports the idea that on-sight climbing requires greater attentional demand compared to red-point climbing, and this may contribute to the development of better attention. This is an important finding that may indicate that the on-sight climbing style could have a considerable positive learning effect on attention, which could be an important component of competitive climbing performance. However, further research is needed to assess if this learning effect exists and whether it can be trained. As such, coaches and trainers should consider including strategies based on practicing on-sight climbing styles instead of the red-point climbing style.

The findings of the current study may help explain why better climbers are less affected by anxiety during an on-sight ascent as seen in previous studies (e.g., Draper et al., 2011b). Further, greater attention accuracy in better climbers could imply a better climbing efficiency or perceptual motor performance (efficient exploration and decrease in the number of typical exploratory movements) (Orth et al., 2017). This could be very important for competitive climbing, given that international competitions use on-sight climbing and a grade of 0.4 (IRCRA) separated the top four competitors in the 2015 International Federation Sport Climbing World Cup (Fryer et al., 2016). We have reported a larger association than a grade between attention and on-sight climbing ability. This is another key finding that could suggest that attention or attentional demands may be important aspects of competitive rock climbing performance. However, the small R^2 (0.14 and 0.32) still supports the concept that climbing performance is a multifactorial sport. As such, there are likely to be other cognitive skills (working memory, inhibitory control, cognitive flexibility, reasoning, etc.) or attentional functions (alert, orienting, or executive control) (Roca et al., 2018) that might explain large percentages of variance that we have not measured in the current study. However, our finding is still important given that at the top level in climbing, marginal gains are key to success.

While this research has presented important and unique findings, to fully contextualize the data, several limitations should be acknowledged. We performed power analyses on the multiple regression models presented in this study. For a level of significance of 0.05, with the current sample size, taking into account the R^2 of all the covariates in the model and the number of covariates, we observed a power of 64.9–84.8% for the main models. The experimental design allows us to reveal how the variables are related, but it does not allow us to detect possible cause–effect relationships. In addition, this study does not allow us to determine whether there are any differences between climbers and non-climbers. Given these points, future research should (1) increase the sample size, (2) conduct an intervention to confirm whether improving the ability of a climber actually improves execution in attention or even knowing whether climber with better attention is less affected by anxiety, and finally (3) study possible differences in attention as a consequence of climbing training between climbers and non-climbers.

CONCLUSION

In summary, our results suggest that after controlling for potential confounding factors (sex, age, climbing experience, and CRF), attention measured objectively is positively related to on-sight, but not red-point, climbing ability. This may be explained by the different ascent characteristics; in particular, the greater attentional demands of on-sight lead climbing may be due to the lack of information regarding the route. The lack of association between RT and climbing performance may be due to the self-paced nature of the sport, as little external temporal demand is placed on the athlete. Rock climbers and their coaches should consider attentional training for on-sight climbing performance in order to increase or maintain climbing ability.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Comité de Ética para la Experimentación Biomédica y de Evaluación de Experimentación con Organismos Modificados Genéticamente (CEED/OMGs) from Cadiz University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

IG-P wrote the first draft of the manuscript. VE-R performed the statistical analyses and together to SF and DG conceived and designed the study and contributed to manuscript development and writing until manuscript was submitted in its final version. JG-R has contributed to the reading and suggestions of the final version.

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The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ANNEX II. COGNITIVE FUNCTION OF CLIMBERS: AN EXPLORATORY STUDY OF WORKING MEMORY AND CLIMBING PERFORMANCE.

Cognitive function of climbers: an exploratory study of working memory and climbing performance

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Abstract

Sport climbing requires a combination of physical and cognitive skills, with working memory (WM) playing a crucial role in performance. This study aimed to investigate the relationship between WM capacity and climbing ability, while considering confounding factors. Additionally, it compared differences in prefrontal cortex (PFC) hemodynamic responses between different ability groups in climbing and sex. Twenty-eight climbers participated, with WM assessed using the eCorsi task and PFC hemodynamic responses measured by near infrared spectroscopy. Linear regression analyses revealed a significant negative relationship between WM and climbing ability. Significant differences were observed between expert and elite climbers as well as female and male in PFC hemodynamic responses. These findings suggest that climbers with higher WM capacity may prioritize threatening information, while higher-skilled climbers may have relatively smaller WM capacity compensated by attentional control and enhanced learning abilities. Hemodynamic responses in the PFC supported these differences. The study sheds light on the role of WM capacity in climbing performance and highlights the potential for training interventions targeting attention and memory.

Keywords: memory forward; executive function; climbing; brain activity; embedded processes model of working memory

Introduction

Sport climbing is a sport that requires a combination of physical and cognitive skills [1], [2]. One cognitive function that has received attention in the context of sport climbing is working memory (WM) [3], [4]. WM refers to the process of actively holding and manipulating relevant information for short periods of time to perform cognitive processes such as planning and reasoning, which are useful in guiding behavior [1]. The capacity of WM is limited, typically encompassing around 3 to 5 chunks of information, and this can vary among individuals [2]. The efficiency of WM is influenced by attentional control and its interaction with information from both short- and long-term memory. This information acts as a guide for determining which data is selected and loaded into WM, as postulated by the embedded-processes model [2].

Researchers have used the dual task paradigm to explore the functional role of WM in the planning and execution of motor skills among climbers [3], [4]. This paradigm requires participants to simultaneously perform two cognitively demanding tasks, such as climbing while recalling a list of words. When both tasks compete for WM processing and storage demands, performance tends to be less efficient than when tasks are performed individually [5]. The decline in climbing performance during a dual-task [6], [7] underscore the role of WM in managing information relevant for planning motor sequences. However, while the involvement of WM in climbing has been observed [6], [7] and differences in attentional control related to climbing ability have been identified [8], the evidence on WM capacity in climbers of different abilities remains unclear [9], [10].

In a study by Heilmann [10],WM was evaluated using the Corsi block task in a group of 19 climbers with varying abilities (9 females). The self-reported climbing ability of expert climbers ranged from 6c+ to 7b, while novice climbers ranged from 5 to 6a on the French climbing grade scale. The results revealed that expert climbers had significantly lower WM capacity (5.33 capacity span) compared to novice climbers (6.50 capacity span). These findings suggest that experts rely less on WM and more on their motor skills and experiences in sport climbing. In contrast, Whitaker et al., [9] found no differences in WM, as measured by the operation span task, between climbers of different abilities in a sample of 34 climbers (20 females) with self-reported climbing ability ranging from 6a+ to 8b. These contrasting findings indicate that the relationship between WM and climbing is complex and may depend on other factors, such as sex, age, education, or climbing experience. Further research is needed to better understand the role of WM in sport climbing and its contribution to climbing performance.

Neuroscience research suggests that the Prefrontal Cortex (PFC) plays a critical role in WM [13], [14]. Near infrared spectroscopy (NIRS) has been used to assess cerebral oxygenation and identify neural activation during WM tasks in the PFC [15]. Studies have observed that better WM performance is associated with a significant increase in oxygenated hemoglobin (O_2Hb) and deoxygenated hemoglobin (HHb) in the PFC, as measured by NIRS [14], [16]. Conversely, individuals with higher WM capacity may exhibit reduced PFC O2Hb, indicating greater neural efficiency compared to those with lower WM capacity [12]. Therefore, understanding the hemodynamic changes in the PFC during a WM task may provide insights into the role of WM capacity in climbing performance.

The present study aims to investigate the relationship between WM capacity and climbing ability, taking into account other factors that may influence this relathionship. Additionally, the study aims was to compare differences in PFC hemodynamic responses during a WM task among different ability groups in climbing, as well as females and males.

Methods

Participants

Twenty-eight rock climbers (5 female), aged from 24 to 49 yrs., with a mean climbing experience of 14.0 years (range, 3 to 30 years) volunteered to participate in the study. The participants' anthropometric and demographic data are described in Table 1. All participants were healthy, non-smokers and not taking any medications that could affect vascular functioning. Exclusion criterion included a history of neurological or psychiatric disorders, as well as substance abuse or dependence. The study received ethical approval from the University Ethics Committee. The data for this study were collected from the High-Performance International Rock-Climbing Research Group (C-HIPPER).

Self- Reported Climbing Ability

Self-reported climbing ability has been used extensively within the literature [8] and validated by Draper et al., [17]. The authors proposed a 3:3:3 rule for reporting climbing grades in research. That is, the climbers' highest grade for which they have completed 3 successful ascents on 3 different routes (at the grade) within the previous 3 months [17]. In accordance with the Position Statement by the International Rock Climbing Research Association (IRCRA) [18], performance grades were converted from French Sport to specific numerical values (IRCRA grades) for all statistical analysis. The sex-specific 75th percentile of on-sight climbing ability was used to describe the sample into expert (<75th) and elite (>75th) climbers.

Working Memory

The digital version of the Corsi-block task (eCorsi) was administered using an experimentally validated open-source software system called PEBL [19] to measure WM. The WM task was conducted on a laptop with a Lenovo 15-inch color screen in an environmentally controlled exercise laboratory. The WM task began with an encoding period, during which participants were presented with sequences of two squares. The series length gradually increased up to 9 squares, with two sequences were presented for each series length. The squares were flashed on a background black screen for 1000 miliseconds, with an inter-stimulus interval of 1000 miliseconds. During the retrieval period, participants were instructed to immediately reproduce the same sequence of blue squares in the same order as they were presented. If at least one square in the sequence was reproduced correctly, the next two trials increased the length of the sequence. The task concluded if participants failed two consecutive trials. Several measurements were recorded to assess participants' performance, such as WM capacity, that refers the number of blocks in the longest correctly reproduced sequence; error rate that represents the total number of incorrect responses; hit reaction time (RT) for corrects answers, that measures the speed of response for correctly reproduced sequences in miliseconds; and errors RT, that captures the speed of response for incorrect answers in miliseconds).

It is important to note that the WM task used in this study focuses on short-term memory and does not directly address the more complex information manipulation processes associated with WM. The task parameters and recorded measurements were based on standardized instructions to ensure consistency and comparability with previous research. The forward version of the WM task was employed, where participants reproduced the sequences in the same order as they were presented. This version of the task was chosen to assess participants' visuospatial working memory capacity in relation to sport climbing performance.

Prefrontal Cortex Perfusion

PFC perfusion was monitored using continuous-wave near infrared spectroscopy (NIRS) NIRO-200NX [15]. The optode probe was positioned at Fp2 and at Fp1 locations, following the International 10-20 system of electrode placement [20]. To minimize signal contamination from ambient light, the optode was covered with a dark opaque cloth, as recommended by the manufacturer. NIRs technology relies on the relative transparency of tissue to infrared light and the oxygen-dependent absorption characteristics of hemoglobin. The device operates at three wavelengths (735, 810 and 850 nm) to detect relative perfusion changes.

During the WM task, NIRs measurements were recorded continuously at 0.5-second intervals. The parameters assessed included the concentration changes in oxygenated hemoglobin (O_2Hb), deoxygenated hemoglobin (HHb), and total hemoglobin (tHb) - referred to as perfusion-, as well as the tissue oxygenation index (TOI) during the encoding period. Delta (△) values for tHb, O_2Hb, HHb and TOI were calculated as relative changes with reference to a zero point. Statistical analyses were performed using values obtained during the baseline (two first trials) and the last two trials of the encoding period.

Statistical Analyses

Prior to analysis, all variables were assessed for heteroscedasticity by examining the variance of the residuals, normal distribution using the Shapiro–Wilk goodness-of-fit test, and equal variance using Levene’s test. All variables were found to be homoscedastic, normally distributed, and exhibited equal variance. To describe the sample, mean differences in categorical and continuous variables between expert vs elite on-sight climbing categories and between female vs male were examined using chi-square or analysis of variance (ANOVA), respectively. Linear regression analysis was employed to examine the relationship between WM measurements and on-sight climbing ability. Confounding variables (sex, age, climbing experience or education level), known to be associated with WM [11] and at the same time exhibiting a change in *ß* coefficients greater than 10%, were included in the regression analyses. Interaction factors (i.e.

climbing ability x main exposures) were assessed using the chunk test [22]. As no significant interactions were observed, all climbers were analyzed together. Multicollinearity was assessed in all models used in this study. The variance inflation factor was below 10, and averaged variance inflation factor was close to 1 [23], indicating the absence of multicollinearity. The relationship of WM and climbing ability was examined using four adjustment models. Model 1 was adjusted for sex, Model 2 was adjusted for sex and age, Model 3 was adjusted for sex and climbing experience, and Model 4 was adjusted for sex and education level. Furthermore, a sensitivity analyses was conducted among male participants only to assess the robustness of the associations between WM and climbing ability, considering the limited number of female participants in this study.

Statistical analyses were performed using STATA version 13.1 (Stata Corp, College Station, TX, USA).

Results

Baseline characteristics

Mean age of the participants was 37.5 years (range, 24.2 to 49.8 years) and they had a climbing experience of 14.0 years (range, 3 to 30 years). Descriptive characteristics of the study population according to the whole sample, climbing ability (expert vs elite) and sex (female vs male) are given in Table 1. Onsight climbing ability was significantly higher for elite compared to expert climbers ($p < 0.001$) and, for male compared to female climbers ($p < 0.001$). Moreover, male climbed significantly more days per week than female ($p < 0.05$). WM measurements characteristics of the study population according to the whole sample, climbing ability (expert vs elite) and sex (female vs male) are given in Table 2.

Multiple regression coefficients (b), unstandardized regression coefficient (β), 95% confidence intervals (95% CI) and *P*-value (*p*) examining the relationship between WM and climbing ability are shown in Table 3. Negative significant associations were found between WM capacity and climbing ability for all models (values range: b from -0.611 to -0.499; β from -0.153 to -0.118; standard error (SE) from 0.05 to 0.06; $p < 0.05$ for all models). Further, positive significant associations were also reported between error reaction time and climbing ability for all models (values range: b from 0.484 to 0.810; β from 28.089 to 46.547; SE from 12.05 to 12.88; $p < 0.05$). Error rate was negatively associate with climbing ability when sex and education (model 4) was taking into account in the model (b: -0.487; β: -0.157; SE: 0.07 $p<0.05$). Non-significant associations were found for hit reaction time and climbing ability ($p > 0.05$).

Similar results were obtained when we analyzed the association of WM measurements and climbing ability only in male participants (n=23); for example, the associations for WM capacity and climbing ability reported a values range for all models (values range of -0.583 to -0.524 for b; from -0.168 to -0.145 for β; from 0.05 to 0.06 for SE and all $p < 0.05$; (data not shown).

Hemodynamic changes (mean and standard deviation) in the PFC during the WM task of the entire sample, categorized by climbing ability and sex are presented in Table 4. Significant differences were found between expert and elite climbers in HHb levels in both Fp1 (MD = -0.80; 95% CI = [-1.43, -0.71]; $p = 0.007$) and Fp2 (MD = -0.78; 95% CI = [-1.34, -0.23]; $p = 0.003$), as well as in O2Hb levels in Fp2 (MD = 1.23; 95% CI = [-0.17, 2.63]; $p = 0.04$) during the WM task. Sex differences were also observed in HHb levels in both Fp1 (MD = 0.75; 95% CI = [-0.06, 1.56]; $p = 0.03$) and Fp2 (MD = 1; 95% CI = [0.33, 1.67]; $p = 0.002$), as well as in O2Hb levels in Fp1 (MD = -1.59; 95% CI = [-3.18, 0.003]; $p = 0.02$).

Figure 1 shows the oxi-and de-oxygenation changes in the right prefrontal cortex of male and female climbers with different climbing abilities and WM capacities during the WM task.

Discussion

Rock climbing is a physically demanding activity that requires individuals to navigate complex routes, make quick decisions, and execute precise movements to ascend rock faces successfully. These cognitive demands necessitate the effective utilization of WM, which enable climbers to hold and manipulate information about their environment and plan their actions accordingly. WM capacity is believed to play a crucial role in supporting the cognitive skills necessary for climbers. Thus, the primary objective of the present study is to investigate the relationship between WM capacity and climbing ability, considering potential confounding factors (sex, age, education level or climbing experience). Furthermore, the study aims to compare differences in WM capacity and PFC hemodynamic responses during a WM task between experts and elite climbers, as well as between female and male. Our findings revealed a negative association between WM capacity and on-sight climbing ability, even after controlling for these confounding factors. These results are consistent with a previous study by Heilmann [10], which demonstrated that novice climbers outperformed expert climbers in a WM task (eCorsi task) that quantify WM span score.

Two hypotheses were proposed to explain these findings. First, it is possible that WM capacity serves as an adaptive function for self-preservation, where lower-ability climbers may perform better due to naturally greater WM capacity. Previous literature has suggested that higher WM capacity may lead to increased visual attention in detecting dangerous stimuli (Wood et al., 2016) and, emotional stimuli in WM negatively interfere with climbing performance (Green et al., 2014). Therefore, our first hypothesis suggests that climbers with higher WM capacity may prioritize threatening information (i.e., falling distance) in WM, which could impair their climbing performance.

The second hypothesis, based on the "embedded-processes model of WM" (Cowan, 2010), posits that higher-skilled climbers develop a relatively smaller WM capacity but compensate for it with better attentional control and information stored in short- and long-term memory through repeated practice of climbing (climbing experience). This model suggests a dynamic relationship between WM, attention and long-term memory, where a smaller WM capacity may be a strength resulting from enhanced learning abilities, and compensatory mechanisms of attentional control and long-term memory would contribute to more efficient WM functioning (Cowan, 2010). Previous findings support this hypothesis, indicating that skilled climbers employ a behavioral gaze strategy (Grushko & Leonov, 2014), exibit better attentional control (Garrido-Palomino et al., 2020), and have superior short-term memory for recalling holds and movement sequences (Whitaker et al., 2019).

Our data also revealed a negative relationship between error rate during the WM task and climbing ability, when considering sex and education. In contrast to our findings, Whitaker et al., (Whitaker et al., 2019) did not find any differences in error rate between expert and elite climbers using the eCorsi task. These conflicting results may be influenced by confounding factors such sex and education level. For example, previous studies have shown that females committed fewer errors than male during WM task (Duff & Hampson, 2001), and higher educational level have a positive effect on preventing error rate (Zarantonello et al., 2020). Moreover, our findings align with the literature suggesting that large set sizes in WM tasks, typically involving more than three or four items, can lead to imprecise memories become and increased errors occurrence (Baddeley, 2003). The lower error rates observed in climbers higher ability level may explain their more spatially efficient route progression and a reduced exploratory behaviors (Orth et al., 2017).

Interestingly, our results showed a positive relationship between error time and climbing ability (Table 2). Previous research has suggested that longer RT to wrong answers reflects the detection and processing of cognitive conflict, including conflict resulting from errors (Botvinick & Braver, 2015). It has also been proposed than error recognition is loaded into WM during motor performance or motor learning to update the motor plan for subsequent actions (Seidler et al., 2012). Larger RT errors could indicate a more efficient behavior of WM for error detection in elite climbers compared to expert climbers (Falkenstein et al., 2000).

Regarding our secondary aim, we investigated differences in PFC hemodynamic responses during the WM task between expert and elite climbers. We found significant differences between the two groups. Expert climbers showed increased O_2Hb concentration in Fp2, while HHb decreased in both Fp1 and Fp2 as WM load increased. These findings suggest increased delivery or increased metabolic demand in the PFC, reflecting higher WM performance in expert climbers. These results are consistent with previous functional magnetic resonance imaging studies that have found positive correlation between better WM performance and increased PFC activation (McNab & Klingberg, 2008) (Causse et al., 2017). The observed hemodynamic changes likely reflect neural activity in response to the mental workload and greater difficulty experienced by expert climbers during the WM tasks. Additionally, the differences in PFC hemodynamic responses between male and female climbers during the WM task, in the absence of WM capacity differences, align with previous studies supporting sex-specific PFC activation in WM function (Li et al., 2010). Overall, our study sheds light on the role of WM capacity in climbers' performance and may have practical application, particularly in the early stages of learning. In line with the theory of the “embedded-processes model of WM” (Cowan, 2010), enhancing short- and long-term memory, as well as attention training, during the initial learning phase, could contribute to more efficient functioning in climbing . This could involve strategies such as memorizing routes and movements sequences or learning to focus attention on critical elements for climbing progression. However, future research is needed to confirm these potential benefits and explore WM capacity is like in female climbers of varying ability. By considering these factors, climbers, coaches, and trainers can optimize their training approaches and improve in climbing activities.

In order to fully contextualise the findings, we need to recognise both the limitations and strengths of this study. Firstly, the sample size was relatively small, which may limit the generalizability of the findings. A larger sample would provide a more representative picture of the climbing population and enhance the robustness of the results. Secondly, the cross-sectional design employed in this study prevents the establishment of causal relationship. A longitudinal or experimental design would offer a deeper understanding of the influence of WM capacity on climbing performance. Additionally, while efforts were made to control for confounding factors such as, sex, age, education level, and climbing experience, it is important to acknowledge the potential influence of uncontrolled factors, including mood, motivation, and general cognitive abilities. Despite these limitations, the study also possesses strengths. Firstly, it successfully controlled for several confounding factors, enhancing the internal validity of the study, and enabling a more accurate analysis of the relationship between WM capacity and climbing performance. Secondly, this study contributes to an emerging area of research by replicating and expanding upon a previous study on WM in the climbing field (Heilmann, 2021). By replicating the findings of Heilmann’s study, our research provides further evidence and insights into the influence of confounding factors on WM capacity in the context of climbing performance. Lastly, the study explored additional measures related to WM capacity, such as error rate, RT and hemodynamic responses in the PFC. These additional measures provide a more comprehensive understanding of the relationship between WM capacity and climbing performance. Furthermore, future research should investigate whether the observed differences in WM between climbers of different skill levels, as measured in a laboratory task, are maintained when measured in a sport context, such as climbing on a rock or artificial climbing wall. This would provide valuable insights into transferability of WM capacity from controlled laboratory setting to real-world climbing scenarios.

Conclusion

To summarize, this study shows differences in the cognitive function of climbers, which contribute to understanding the cognitive processes underlying the behavior of the most successful climbers. Our results provide evidence of differences in climbers´ WM capacity, which is negatively associated to on-sight climbing ability. Furthermore, differences in WM capacity between expert and elite climbers seem to be supported by differences in PFC hemodynamic responses. Such differences in WM could be explained according to the "integrated WM process model", which postulates that the limit of WM could be a strength indicating more efficient functioning. However, differences between male and female climbers in PFC hemodynamic responses seem suggest sex-specific PFC activation under WM function. While further research is still necessary, climbers, coaches and trainers should consider the type and amount of information climbers load into their WM during climbing to prevent errors, enhancing short- and long-term memory and attention training in early stages.

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Disclosure statement

The authors report there are no competing interests to declare.

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Tables

Table 1.

Descriptive Characteristics of the Entire Sample, categorized by Climbing Ability and by Sex.

	All sample (n=28)	**Expert** (n=19)	**Elite** (n=9)	**Female** (n=5)	**Male** (n=23)
Age (yrs.)	37.5 ± 6.6	37.3 ± 6.7	37.9 ± 6.3	38.1 ± 3.8	37.3 ± 7.3
Weight (kg)	69.9 ± 10.9	72.9 ± 10.7	64.1 ± 9.3*	55.4 ± 5.4	73.2 ± 9.0**
Height (m)	172.8 ± 8.4	173.4 ± 6.8	171.6 ± 11.3	159.8 ± 4.6	175.7 ± 5.9**
BMI (kg/m2)	23.4 ± 3.2	24.2 ± 3.4	21.7 ± 1.2	21.7 ± 2.2	23.8 ± 3.3
University studies (%)	39.3	44.4	30	16.7	45.5
Climbing experience (yrs.)	14.0 ± 9.3	12.1 ± 8.6	17.6 ± 10.0	11.7 ± 9.5	14.6 ± 9.4
Climbing days per week	1.8 ± 0.9	1.9 ± 0.9	1.6 ± 0.8	1.2 ± 0.8	2.0 ± 0.8*
On-sight Climbing range (French scale)	V+ to 7c+	V+ to 7a+	6c to 7c+**	V+ to 7a	6a+ to 7c+**

Data presented as mean ± standard deviation. * $p < 0.05$, ** $p < 0.00$

Table 2.

Descriptive Characteristics of Working Memory Task Performance for the Entire Sample, Categorized by Climbing Ability (Expert Vs Elite), and Sex

	All sample (n=28)	**Expert** (n=19)	**Elite** (n=9)	**female** (n=5)	**Male** (n=23)
Working Memory Capacity (Span score)	5.6 ± 0.8	5.8 ± 0.8	5.2 ± 0.7	5.5 ± 0.9	5.6 ± 0.8
Error Rate (Number of incorrect responses)	3.0 ± 0.9	3.2 ± 0.8	2.7 ± 1.0	3.0 ± 1.2	3.0 ± 0.9
Hit Reaction Time (Miliseconds)	590.3 ± 116.3	582.2 ± 111.8	607.5 ± 130.5	559.7 ± 54.3	597.0 ± 125.7
Error Reaction Time (Miliseconds)	655.4 ± 195.3	608.6 ± 194.4	754.1 ± 165.8	551.5 ± 77.3	677.4 ± 195.3

Data presented as mean ± standard deviation.

Table 3.

Multiple Lineal Regression Coefficients Examining the Relationship of Working Memory and Climbing Ability.

	Working Memory Capacity (Span score)				**Error Rate** (Number of incorrect responses)				**Error Reaction Time** (Miliseconds)				**Hit Reaction Time** (Miliseconds)			
	b	**β**	**95% IC**	***p***	**b**	**β**	**95% IC**	***p***	**b**	**β**	**95% IC**	***p***	**b**	**β**	**95% IC**	***p***
Model 1	**-0.558**	**-0.138**	**-0.25 to -0.03**	**0.014**	-0.393	-0.126	-0.26 to 0.01	0.069	**0.534**	**31.310**	**6.49 to 56.13**	**0.016**	0.097	3.374	-13.65 to 20.40	0.687
Model 2	**-0.535**	**-0.132**	**-0.25 to -0.02**	**0.026**	-0.435	-0.139	-0.29 to 0.01	0.059	**0.527**	**30.888**	**4.31 to 57.47**	**0.025**	0.083	2.912	-15.31 to 21.14	0.744
Model 3	**-0.611**	**-0.153**	**-0.28 to -0.02**	**0.022**	-0.401	-0.128	-0.29 to 0.04	0.124	**0.810**	**46.547**	**21.04 to 72.05**	**0.001**	0.336	11.243	-7.47 to 29.960	0.226
Model 4	**-0.499**	**-0.118**	**-0.23 to -0.01**	**0.038**	**-0.487**	**-0.157**	**-0.30 to -0.02**	**0.030**	**0.484**	**28.089**	**1.77 to 54.41**	**0.037**	0.128	4.561	-13.71 to 22.83	0.611

Data are presented as standardized regression coefficient (b), unstandardized regression coefficient (β), 95% confidence interval (95% CI), and P-value (P).
Model 1 was adjusted for sex.
Model 2 was adjusted for sex and age.
Model 3 for sex and climbing experience (years).
Model 4 for sex and education.
Statistically significant associations are in bold.

Table 4.

Hemodynamic Changes (Mean and Standard Deviation) in the Prefrontal Cortex During the Working Memory Task of the Whole Sample, Categorized by Climbing Ability (Elite Vs Expert) and Sex.

	All sample (n=28)	**Expert** (n=19)	**Elite** (n=9)	**Female** (n=5)	**Male** (n=23)
Left Prefrontal Cortex (FP 1)					
△tHb (uM)	1.14 ± 1.41	0.76 ± 1.44	1.94 ± 1.00*	0.59 ± 1.58	1.26 ± 1.38
△O_2Hb (uM)	2.48 ± 1.66	2.42 ± 1.91	2.60 ± 1.04	1.17 ± 1.66	2.76 ± 1.55*
△HHb (uM)	-1.20 ± 0.84	-1.45 ± 0.87	-0.65 ± 0.39*	-0.58 ± 0.27	-1.33 ± 0.86*
△TOI (%)	0.80 ± 1.15	0.89 ± 1.28	0.60 ± 0.83	0.13 ± 0.70	0.94 ± 1.19
Right Prefrontal Cortex (FP 2)					
△tHb (uM)	1.08 ±1.53	1.17 ± 1.51	0.88 ± 1.66	0.95 ± 1.06	1.11 ± 1.64
△O_2Hb (uM)	2.43 ± 1.75	2.82 ± 1.81	1.59 ± 1.36*	1.37 ± 1.14	2.66 ± 1.80
△HHb (uM)	-1.24 ± 0.75	-1.50 ± 0.72	-0.71 ± 0.54*	-0.42 ± 0.28	-1.42 ± 0.70*
△TOI (%)	0.63 ± 1.44	0.73 ± 1.65	0.43 ± 0.89	-0.03 ± 0.93	0.78 ± 1.50

Hemodynamic changes (△) were calculated as resulting of the difference between baseline values (two first trials) and those sampled during the last two trial of working memory task.

*p<0.05 indicating significant different the from expert climbers

uM= 10^{-6}mol/L

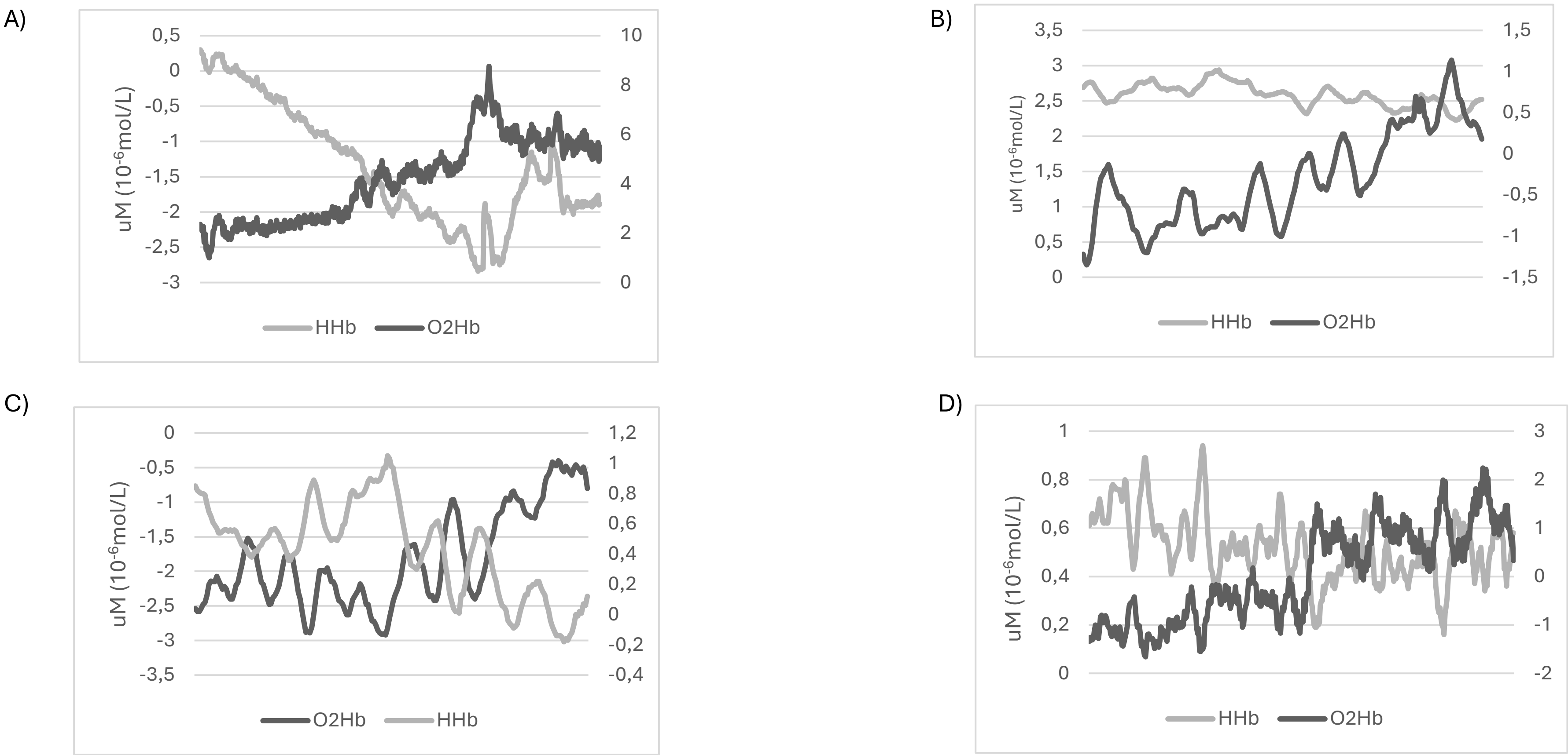

Figure. 1.

Oxi- and De-Oxygenation Changes in Right Prefrontal Cortex of Male and Female Climbers with Different Climbing Ability and Working Memory Capacity during Working Memory Task. (A) Expert Male Climber (6b+ On-Sight Climbing Ability) with 7 Span of Working Memory Capacity. (B) Elite Male Climber (7b+ On-Sight Climbing Ability) with 5 Span of Working Memory Capacity. (C) Expert Female Climber (5+ On-Sight Climbing Ability) with 4.5 Span of Working Memory Capacity. (D) Elite Female Climber (6c On-Sight Climbing Ability) With 6.5 Span of Working Memory Capacity.

Supplementary material

Table 1.

Analysis of Normality and Homogeneity of Variances for all Variables.

	Shapiro-Wilk test		**Levene's Test**	
	W	*p*	W0 or χ^2	*p*
Descriptive Characteristics				
Age (yrs.)	.96	.298	.24	.627
Weight (kg)	.96	.424	.04	.843
Height (m)	.96	.570	5.31	.030
Body Mass Index (kg/m2) ^	.93	.073	.74	.398
Education Level (%)	.689 [a]		.56[b]	.453
Climbing Experience (yrs.) ^	.93	.060	.30	.590
Climbing Days per Week	.99	.965	.01	.920
Climbing Ability	.97	.496	.64	.431
Working Memory Task measures				
Working Memory Capacity (Span score)	.98	.761	2.20	.150
Error Rate (Number of incorrect responses)	.94	.124	.91	.349
Hit Reaction Time (Milliseconds)	.95	.159	.33	.570
Error Reaction Time (Milliseconds)	.95	.253	.03	.866
Left Prefrontal Cortex (FP 1)				
Total Hemoglobin	.94	.091	.32	.579
Oxygenated Hemoglobin	.96	.334	1.61	.215
Deoxygenated hemoglobin	.90	.011	7.10	.013
Tissue oxygenation index	.98	.787	1.36	.254
Right Prefrontal Cortex (FP 2)				
Total Hemoglobin	.95	.260	.09	.760
Oxygenated Hemoglobin	.97	.522	.76	.392
Deoxygenated hemoglobin	.94	.135	.30	.588
Tissue oxygenation index	.96	.268	1.43	.242

^ inverse square root transformed

[a] Fisher´s exact test

[b] χ^2 from Chi-square test

Table 2.

Interaction Analysis of Confounding Variables Sex, Age, Climbing Experience, and Education Level for Different Regression Analyses.

		β	95% IC		t	p	Chunk Test	
			LL	UL			$F_{(1, 24)}$	p
Working Memory Capacity (Span score)	Climbing ability x Sex	-.224	-.55	.10	-1.43	.65	2.05	.165
	Climbing Ability x Age	-.0002	-.69	.55	-.03	.977	0	.977
	Climbing Ability x Climbing Experience (years)	-.005	-.02	.006	-.96	.349	.91	.349
	Climbing Ability x Education Level	-.043	-.28	.19	-.38	.71	.15	.705
Error Rate (Number of incorrect responses)	Climbing ability x Sex	.090	-.26	.44	.52	.606	.27	.606
	Climbing Ability x Age	-.011	-.03	.01	-1.01	.323	1.02	.323
	Climbing Ability x Climbing Experience (years)	-.008	-.02	.006	-1.15	.261	1.33	.261
	Climbing Ability x Education Level	.053	-.27	.38	.34	.740	.11	.740
Error Reaction Time (Milliseconds)	Climbing ability x Sex	26.68	-50.46	103.84	.71	.482	.51	.482
	Climbing Ability x Age	-2.06	-5.57	1.45	-1.21	.239	1.46	.239
	Climbing Ability x Climbing Experience (years)	.14	-2.07	2.34	.13	.896	.02	.896
	Climbing Ability x Education Level	12.34	-40.73	65.41	.48	.635	.23	.635
Hit Reaction Time (Milliseconds)	Climbing ability x Sex	13.21	-39.98	66.40	.51	.613	.26	.612
	Climbing Ability x Age	-.77	-3.24	1.68	-.65	.521	.42	.521
	Climbing Ability x Climbing Experience (years)	.05	-1.54	1.65	.07	.943	.01	.943
	Climbing Ability x Education Level	21.04	-14.85	56.93	1.21	.238	1.47	.238

Table 3

Multiple Lineal Regression Coefficients Examining the Relationship of Working Memory and Climbing Ability for Male (n = 23).

		b	β	95% IC		*t*	*F*	*p*	R^2	Adj R^2
				LL	UL					
	Linear regression model									
Working Memory Capacity (Span score)	Model 1. Unadjusted	-.584	-.165	-.27	-.06	-3.30	10.87	.003*	.341	.310
	Model 2. Adjusted for age	-.536	-.151	-.26	-.04	-2.88	5.76	.009*	.366	.302
	Model 3. Adjusted for climbing experience (years)	-.559	-.165	-.28	-.05	-2.98	5.30	.008*	.358	.291
	Model 4. Adjusted for education level	-.524	-.145	-.25	-.03	-2.76	4.38	.012*	.316	.244
Secondary outcomes										
Error Rate (Number of incorrect responses)	Model 1. Unadjusted	-.369	-.109	-.23	.02	-1.82	3.31	.083	.136	.095
	Model 2. Adjusted for age	-.390	-.115	-.25	.02	-1.80	1.64	.087	.141	.055
	Model 3. Adjusted for climbing experience (years)	-.319	-.096	-.24	.04	-1.44	1.05	.368	.099	.005
	Model 4. Adjusted for education level	-.485	-.146	-.27	-.02	-2.42	2.96	.026*	.238	.157
Error Reaction Time (Milliseconds)	Model 1. Unadjusted	.483	34.527	6.11	62.95	2.53	6.38	.020*	.233	.197
	Model 2. Adjusted for age	.474	33.929	3.39	64.47	2.32	3.05	.031*	.234	.157
	Model 3. Adjusted for climbing experience (years)	.620	44.973	16.98	72.96	3.36	5.81	.003*	.379	.314
	Model 4. Adjusted for education level	.430	31.090	.16	62.02	2.10	2.49	.049*	.208	.124
Hit Reaction Time (Milliseconds)	Model 1. Unadjusted	.114	4.966	-14.64	- 24.57	.53	.28	.604	.013	-.034
	Model 2. Adjusted for age	.095	4.144	-16.90	25.18	.41	.17	.686	.017	- .082
	Model 3. Adjusted for climbing experience (years)	.258	11.102	-9.29	31.50	1.14	.65	.269	.064	- .034
	Model 4. Adjusted for education level	.141	6.446	-15.02	27.91	.63	.39	.537	.040	- .062

Note. Data are presented as standardized regression coefficient (b), unstandardized regression coefficient (β), 95% confidence interval (95% CI), lower confidence interval (LL), upper confidence interval (UL) and P-value (*p*). * p < .05 indicating statistically significant associations.

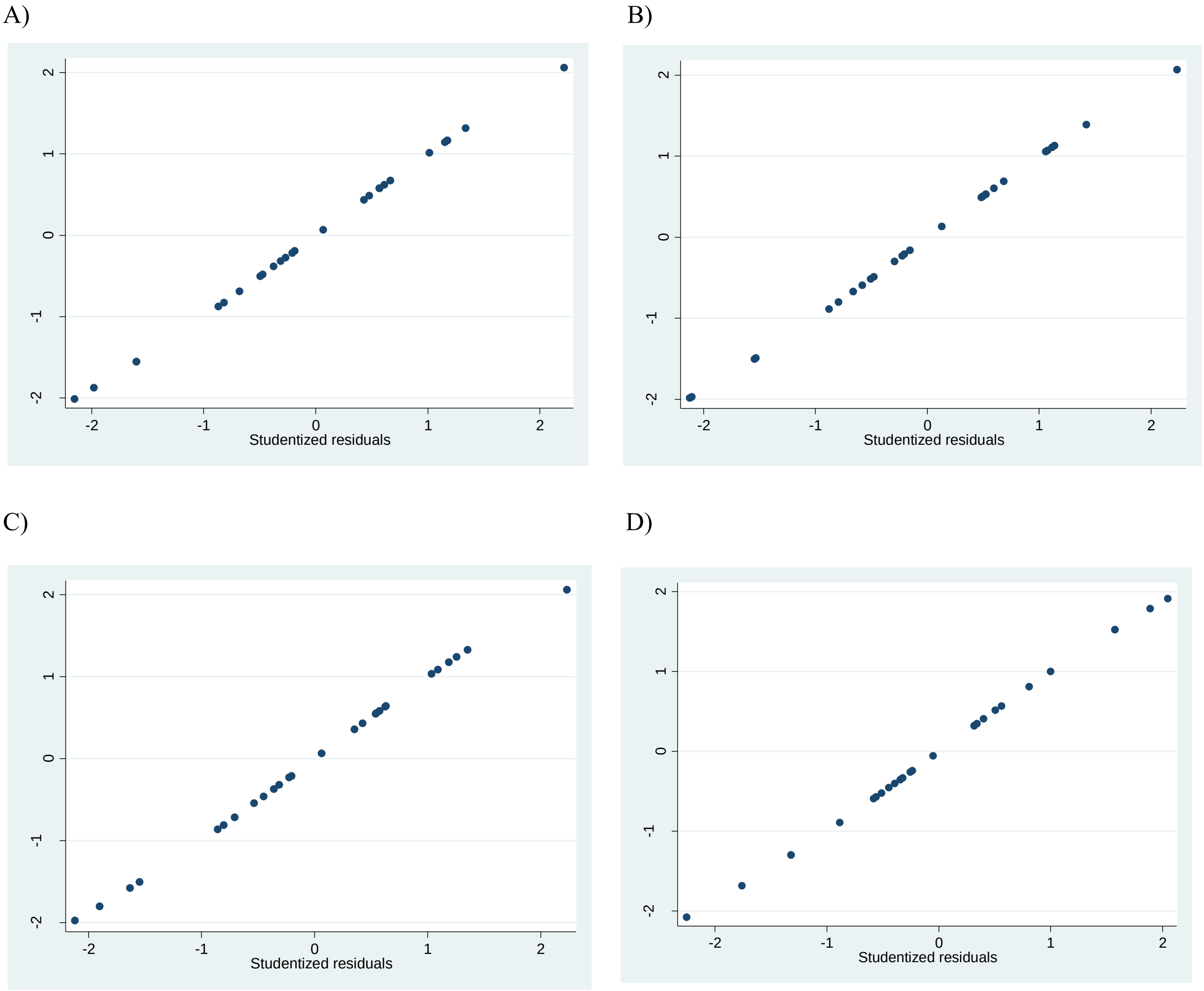

Figure 1.

Analysis of Residuals from the Regression Models (A) Model 1. Adjusted for Sex, (B) Model 2. Adjusted for Sex and Age. (C) Model 3. Adjusted by Sex and Climbing Experience, (D) Model 4. Adjusted by Sex and Education Level.

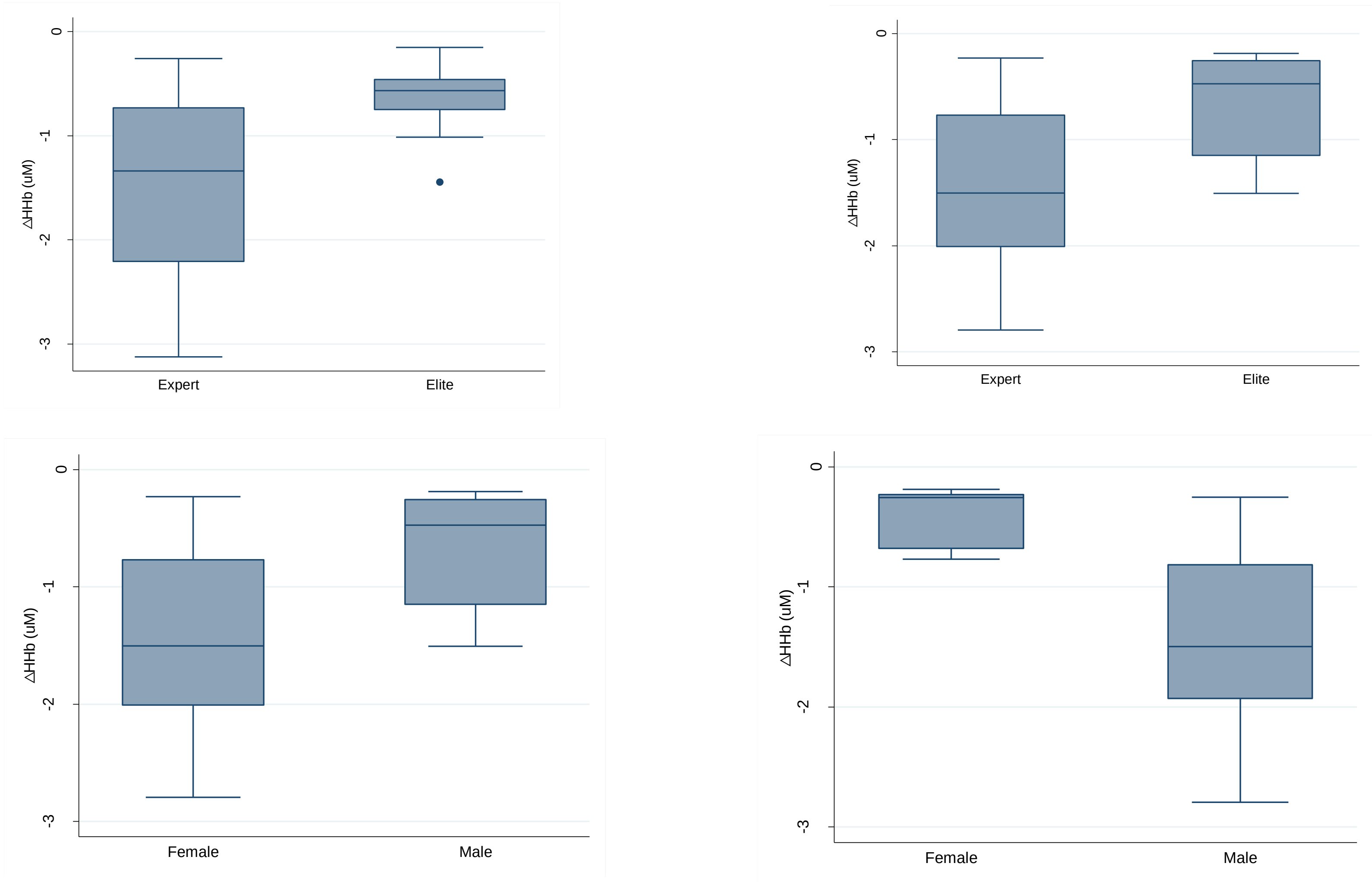

Figure 2

De-Oxygenated Changes in Left and Right Prefrontal Cortex of Expert- Elite and Male-Female Climbers after Completing the WM Task

ANNEX III. AUTONOMOUS AND PORTABLE SYSTEM FOR TRAINING WORKING MEMORY AND CLIMBING TECHNIQUE.

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Expediente: **U202231081**

Título: **SISTEMA AUTÓNOMO Y PORTABLE PARA EL ENTRENAMIENTO DE LA MEMORIA DE TRABAJO Y LA TÉCNICA EN ESCALADA**.

Con fecha 27 de junio de 2022, la Universidad de Cádiz presentó la solicitud de modelo de utilidad de referencia U202231081, el cual fue concedido con fecha 04/10/2023.

En la instancia de solicitud presentada, se incluía un error en el segundo apellido de la primera de las inventoras.

Concretamente, el segundo apellido de la inventora con DNI 26039180Y aparece como "PALOMO", cuando su ortografía correcta es "**PALOMINO"**.

Debido a que se trata de un error manifiesto, recogido en la instancia que remitimos en la solicitud, se ruega la corrección del mismo en virtud del artículo 49 de la Ley 24/2015, de 24 de julio, de Patentes.

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DESCRIPCIÓN

SISTEMA AUTÓNOMO Y PORTABLE PARA EL ENTRENAMIENTO DE LA MEMORIA DE TRABAJO Y LA TÉCNICA EN ESCALADA

SECTOR DE LA TÉCNICA

Esta invención se refiere a un sistema que permite el entrenamiento de la Memoria de Trabajo y la técnica deportiva en el deporte de escalada.

ANTECEDENTES DE LA INVENCIÓN

La escalada es un deporte en auge donde se requiere un gran esfuerzo físico, una técnica depurada y una correcta toma de decisiones. Para el trabajo de este último factor es fundamental el desarrollo de la denominada Memoria de Trabajo, así como los procesos de adquisición, consolidación, mantenimiento y recuperación de la información en la memoria a corto y medio plazo.

La Memoria de Trabajo o memoria operativa, se puede explicar como un conjunto de procesos que nos permiten el almacenamiento y manipulación temporal de la información para la realización de tareas cognitivas complejas. Nos permite tener la capacidad de mantener temporalmente información visoespacial, como pueden ser localizaciones espaciales o secuencias de movimientos. Además, nos posibilita la planificación, ejecución de determinados movimientos y llevar a cabo un comportamiento (Baddeley, 2003). Una característica distintiva de la Memoria de Trabajo es que se considera que tiene una capacidad limitada, porque se supone que la información almacenada con precisión consta de solo 3 o 4 elementos integrados (Baddeley y Hitch, 1974). Cuando se excede el almacenamiento, aumenta el número de errores, lo que reduce la precisión de la información recordada (Almeida, Barbosa, & Compte, 2015; Muthukrishnan, Ahuja, Mehta, & Sharma, 2016; Nee & Esposito, 2016).

Así pues, posee una función fundamental en la planificación y ejecución de movimientos para llevar a cabo una conducta determinada. Distintas investigaciones expresan como la MT es una capacidad limitada y es entrenable (Morrison & Chein, 2011), de ahí la importancia del desarrollo de nuevas técnicas y dispositivos que permitan su entrenamiento.

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Por otro lado, la técnica deportiva, que puede ser definida como el procedimiento desarrollado en la práctica del deporte para resolver una tarea motora determinada de la forma más adecuada, económica y con el mayor rendimiento posible. La técnica deportiva es un tipo motor ideal que puede experimentar modificaciones en función de las circunstancias individuales y de las características de cada deporte.

En la escalada deportiva, debido a las peculiaridades de este deporte, no son muy numerosas las investigaciones realizadas en el campo de la evaluación y entrenamiento de la Memoria de Trabajo, la técnica deportiva y el control del rendimiento físico y menos aún en los desarrollos tecnológicos que lo permitan.

Los métodos utilizados hasta la fecha para el entrenamiento de la Memoria de Trabajo se basan en programas informáticos que reproducen en el ordenador marcas gráficas distribuidas de una forma especifica y que posteriormente el usuario ha de reproducir en un tiempo determinado. Pero dichas marcas gráficas no se reproducen, como es en este caso, sobre un rocódromo, ni están adaptados a la escalada propiamente dicha.

La presente invención tiene por objeto el desarrollo de un sistema que permite entrenar la Memoria de Trabajo y la técnica deportiva mediante el diseño y la reproducción de rutas o trayectorias sobre un rocódromo, que deberá replicar el escalador tras un tiempo de observación determinado.

La originalidad y novedad de esta propuesta radica tanto en la forma en que son generadas las rutas, como en la forma en que estas son proyectadas en el rocódromo.

En cuanto a la generación de las rutas, estas se realizan bien mediante la captación de los datos generados por sensores inerciales colocados en el cuerpo un escalador que realiza previamente una ruta, o bien introduciéndolas manualmente a través de una tableta digitalizadora por parte del entrenador o usuario.

En cuanto a la proyección de las rutas sobre el rocódromo, estas se realizan proyectando una imagen generada por un proyector láser, acompañada de la emisión de estímulos auditivos, como información o instrucciones del entrenador.

Para conseguir su objetivo, el objeto de la invención se compone de un número variable de sistemas inerciales, una tableta digitalizadora/ordenador personal, emisor de sonido, un proyector láser y un software específico que permite proyectar sobre el rocódromo imágenes prediseñadas sobre la ruta a realizar por el escalador, proyecciones para el desarrollo de la Memoria de Trabajo y proyecciones o representaciones anatómicas de posiciones de sus diferentes segmentos corporales durante la escalada.

A continuación, se citan algunas invenciones de métodos de análisis ya registrados, conocidos por el solicitante, que este considera cercanos al objeto de la invención:

US8668626B1: Wireless pressure sensing rock climbing handhold and dynamic method of customized routing. Esta invención se refiere a una presa de escalada que incluye un microprocesador, unos sensores de presión y unos emisores de luz que vía inalámbrica informa sobre las trayectorias que ha de seguir el escalador y la presión de apoyo. En esta invención son las mismas presas las que incorporan sensores de presión, por lo que no se trata de un sistema autónomo del rocódromo, trasladable a otro rocódromo, ya que este debe incorporar dichas presas específicas. Por otro lado, esta invención no permite cuantificar variables cinemáticas del escalador, producidas por el uso de sistemas inerciales para la adquisición de la posición del escalador, su velocidad o su aceleración durante el desarrollo del ejercicio.

WO2008059092A1: Simulador de paredes de escalada. Esta invención se compone de una estructura articulada, cubierta por una superficie formada por paneles preparados y equipados para la práctica de la escalada, la cual está accionada por un sistema motor convencional capaz de mover y fijar una posición determinada del conjunto y mantenerla, gobernado por un dispositivo de control convencional programable, mediante el cual, el usuario selecciona una posición determinada de ascensión del simulador de paredes de escalada, para su empleo, pudiendo fijarse tantas posibilidades de ascensión como el usuario desee practicar.Al igual que la anterior, esta invención no mide parámetros biomecánicos del escalador como la cinemática o el desarrollo de la memoria de trabajo.

ES2055565: Muro de escalada artificial con superficie alabeada modular. Esta invención consiste en un muro de escalada, que comprende varios paneles de formas conjugadas, ensamblados entre sí por medios de fijación para formar una superficie modular. Su configuración es modificable después de la recomposición de los paneles y unos medios de unión de la superficie modular a un soporte fijo, tipo muro o un andamiaje. A diferencia del sistema propuesto, no incorpora sensores de medición cinemáticos (sistemas inerciales), ni la proyección mediante haz de luz láser de recorridos, trayectorias o modelos anatómicos diseñados mediante la tableta digitalizadora o la captación de los sistemas inerciales, por lo que no permite el entrenamiento de la Memoria de Trabajo,

US7381154B1: Heart rate monitors and displays for climbing walls. Esta invención contiene un sistema para monitorizar en una pantalla incorporada al muro de escalada la frecuencia cardiaca que posee el escalador durante la práctica deportiva. Aunque incorpora sensores de medición del pulso cardiaco, no incorpora otros sensores de tipo inercial, ni la proyección de rutas, lo que imposibilita entrenar la Memoria de Trabajo.

US5732954: Route recording, marking, and scoring apparatus for sport climbing walls. Esta invención comprende un sistema de control electrónico para el registro de las rutas que realizan los escaladores durante su actividad deportiva o recreativa, permitiendo mejorar su rendimiento y entrenamiento mediante la grabación de las rutas realizadas previamente. Sin embargo, al igual que los sistemas mencionados anteriormente, esta invención no permite el registro de variables cinemáticas generadas mediante sensores inerciales y el modo de registro de las distintas rutas y trayectorias son diferentes a los que se proponen en la invención presentada. De igual forma, tampoco incluye la proyección mediante luz láser de trayectorias prediseñadas, por lo que no permite el entrenamiento de la Memoria de Trabajo ni. Tampoco incorpora la emisión de estímulos auditivos durante la ejecución del ejercicio.

U1076190: Equipo electrónico de entrenamiento para deportes de escalada. El objeto de la invención se centra en un equipo de entrenamiento orientado a la escalada y que, formado por un conjunto de elementos electrónicos y un ordenador, permite elaborar, guardar y visualizar rutas de escalada en paneles o rocódromos artificiales, por medio de la aplicación de una marca luminosa en los agarres que forman parte de una ruta. Además, se puede detectar la posición del escalador gracias a contactos eléctricos que detectan, por proximidad, partes del cuerpo del escalador. Los contactos en esta invención están vinculados a cada uno de los agarres, permitiendo modificar, en tiempo real, la ruta, así como visualizar varias rutas a la vez. El sistema de iluminación permite diferenciar los agarres utilizando luces proyectadas o, alternativamente, mediante luces incorporadas en el interior de los agarres o presas.

Sin embargo, este sistema no utiliza sensores inerciales colocados en el escalador, sino que utiliza sensores capacitivos y otro tipo de sensores de iluminación colocados en la presa el rocódromo. Por otra parte, la necesidad de usar un tipo de presa determinado, requiere la fabricación o modificación de los agarres del propio rocódromo, lo cual impide que este sistema sea autónomo. A diferencia de esta invención, el sistema objeto de la invención propuesta por el solicitante no precisa la modificación de las presas ni de ningún otro componente del rocódromo.

ES1076190U: Equipo electrónico de entrenamiento para deportes de escalada El objeto de la invención se centra en un equipo de entrenamiento orientado principalmente a la escalada y que, formado por un conjunto de elementos electrónicos y un computador, permite elaborar, guardar y visualizar rutas de escalada en paneles o rocódromos artificiales, por medio de la aplicación de una marca luminosa en los agarres que forman parte de una ruta. Además, se puede detectar la posición del escalador gracias a contactos eléctricos que detectan por proximidad partes del cuerpo del escalador. Los contactos están vinculados a cada uno de los agarres, permitiendo modificar en tiempo real la ruta, así como visualizar varias rutas a la vez. La invención utiliza como alternativa a las presas iluminadas el uso de un proyector láser, sin embargo, su uso es únicamente para el marcado alternativo de las presas. El sistema tampoco permite la realización de modelos anatómicos que posteriormente pueden ser proyectados por el sistema de luz láser, sino que solo permite el marcado de las presas iluminándolas. Adicionalmente, la necesidad de que la luz generada por el proyector incida en una presa determinada obliga al sistema a conocer la ubicación concreta de dicha presa en el rocódromo en el que está instalada, lo cual reduce la autonomía del sistema respecto del rocódromo, como ocurre en el caso de la invención propuesta por el solicitante. Por otro lado, este sistema no incorpora la funcionalidad de introducir manualmente rutas a través de una tableta digitalizadora por parte del entrenador o usuario, ni menciona el uso de emisores de sonidos que permita el trabajo de factores psicológicos como los tiempos de reacción, inicio-fin de prueba, entrenamiento en situación de stress u otras capacidades de la neurociencia y la psicología del deporte.

US8808145B1: Interactive climbing wall system using touch sensitive, illuminating, climbing hold bolts and controller. Es un sistema que utiliza unos pernos de sujeción en cada presa, iluminados y sensibles al tacto con capacidad de detectar la presencia del escalador. Además, el sistema está conectado a Internet donde se configura y permite a los usuarios iluminar una ruta o participar en una amplia variedad de actividades y juegos de capacitación interactivos. A diferencia del sistema objeto de la invención, este dispositivo no permite el entrenamiento de la Memoria de trabajo, no utiliza sensores inerciales para la medición de variables cinemáticas y precisa de la modificación de cada presa para poder iluminarlas y definir rutas.

US2008032863A1: Climbing Wall System. Comprende un rocódromo provisto de varias presas instrumentadas con sensores que permiten detectar la presencia de un pie o una mano cuando es apoyada. Comprende un sistema de sonido para reproducir música y un dispositivo de control que permite reproducir un determinado fragmento musical. Este dispositivo está orientado a la parte más lúdica de la escalada, junto con la reproducción de música y el desarrollo de juegos. No permite el entrenamiento de la Memoria de Trabajo, no posee la capacidad de diseñar rutas o actividades mediante tableta digitalizadora/panel táctil, ni es capaz de medir variables cinemáticas mediante sensores inerciales, lo cual representa una clara diferencia con la presente solicitud.

US2016136496A1: Device for managing the illumination of the grips of a climbing Wall. La invención se refiere a un dispositivo para la gestión de la iluminación de las presas de un rocódromo con el fin de señalizar recorridos en función de la dificultad deseada. El sistema es fijado en la parte posterior de la pared y capaz de emitir un campo electromagnético y una fuente de luz. Al igual que los anteriores dispositivos mencionados requiere la transformación de las presas de escalada, no permite la obtención y el análisis de datos cinemáticos, ni el entrenamiento de la Memoria de Trabajo.

US2019329113A1: Modular interactive climbing wall system using touch-sensitive, illuminated climbing holds, and controller. Este dispositivo utiliza presas de escalada iluminadas y sensibles al tacto, capaces de detectar la presencia de un escalador, localizadas en paneles modulares para crear un entorno interactivo. El sistema está conectado a Internet donde se configura y permite a los usuarios con un dispositivo habilitado para la web participar en una amplia variedad de actividades y juegos. En este sistema nuevamente aparece la presencia de presas iluminadas mediante luces led o similar incluidas dentro de la misma presa. A diferencia de la invención propuesta, la cual utiliza un proyector para marcar o proyectar imágenes en el rocódromo a lo que se suma la obtención de variables cinemáticas y dinámicas del escalador para la mejora de la técnica deportiva, este sistema no permite entrenar la Memoria de Trabajo.

WO2020111461A1: Climbing system on artificial rock Wall. La presente invención se refiere a un sistema de escalada que utiliza una pared de roca artificial, que comprende unos módulos de control, dispuestos de manera fija en el propio rocódromo, presas dispuestas en lugares aleatorios de la pared, sensores cada uno de los cuales detecta que el escalador entra en contacto con cada presa. Al igual que los otros sistemas vistos anteriormente, permite captar información sobre la ruta realizada por el escalador, pero no posibilita la obtención de variables cinemáticas ni dinámicas ni tampoco permite el entrenamiento de la Memoria de Trabajo.

WO2021081053A1: Climbing wall with input based climber feedback outputs and system for delivering climbing paths to multiple climbers on different walls simultaneously. Consiste en un rocódromo con multitud de presas instrumentadas para la detección de cuando el escalador contacta con la presa. Posee un dispositivo de control que permite guiar al escalador a lo largo de la trayectoria que realiza proponiéndole otras alternativas. También permite la medición de la fuerza aplicada en cada presa y el tiempo en la que se ha apoyado en la misma. Al igual que el resto de dispositivos, requiere la instrumentalización o modificación de cada presa, no utiliza sensores inerciales para la medición de variables cinemáticas ni dinámicas y lo que es más importante, no permite la medición o el entrenamiento de la Memoria de Trabajo.

Así pues, no se observa que ninguna de las invenciones anteriormente mencionadas, tomadas por separado o en combinación, permita el entrenamiento de la Memoria de Trabajo ni la técnica de escalada, incluyendo a su vez las ventajas que aporta la invención propuesta por el solicitante, recogidas en esta memoria.

Referencias bibliográficas:

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EXPLICACIÓN DE LA INVENCIÓN

La presente invención consiste en un sistema que permite el entrenamiento de la Memoria de Trabajo:

a) Que requiere de ser empleado en un rocódromo, pero a su vez es autónomo de dicho rocódromo, e independiente y portable permitiendo su funcionamiento en cualquier rocódromo, sin necesidad de realizar ninguna modificación o adaptación de este para el funcionamiento del sistema.

b) Que permite la generación y el registro de rutas de escalada, por dos métodos distintos:
- Mediante la captación de los datos generados por sensores inerciales colocados en el cuerpo un escalador que realiza previamente una ruta.
- Mediante su introducción manual, a través de una tableta digitalizadora por parte del entrenador o usuario.

c) Que permite la proyección de las rutas generadas sobre un rocódromo, proyectando una imagen generada por un proyector láser

d) Que acompaña la proyección de la emisión de estímulos auditivos, pudiendo ser estos de carácter positivo, como pueden ser información o instrucciones del entrenador, o de carácter estresante como puede ser la emisión de sonido ambiente, ruido u otros factores que puedan alterar la técnica del deportista, que permitan el trabajo de factores psicológicos o relacionados con la neurociencia.

La invención es de aplicación para el estudio de la capacidad física, técnica y psicológica de los escaladores, permitiendo cuantificar variables cinemáticas (tiempo, velocidad, aceleración), así como el desarrollo de factores psicológicos con es la memoria de trabajo y la técnica del escalador.

Para la medición de variables cinéticas, la invención incorpora sensores inerciales que son localizados en los segmentos corporales como son las muñecas, tobillos y cintura del escalador y conectados de forma inalámbrica a un ordenador personal cuyo software permite el tratamiento de la señal y reproducir en pantalla los movimientos realizados por el deportista.

Adicionalmente, una tableta digitalizadora, dotada de un software especifico, permite introducir en el ordenador una ruta que ha de realizar el escalador, unas marcas que identifiquen determinadas presas, o cualquier otro dato de interés para el entrenamiento de la Memoria de Trabajo.

Las rutas generadas, ya sea mediante captación de los datos generados por sensores inerciales colocados en el cuerpo un escalador que realiza previamente una ruta, o bien por su introducción manual, a través de una tableta digitalizadora por parte del entrenador o usuario, han de ser proyectadas, por medio de un proyector láser o similar, en la pared del rocódromo durante un tiempo determinado. Tras el paso de ese tiempo tales marcas desaparecen y es el escalador el que ha de ser capaz de reproducir dichas marcas o rutas bien escalando sobre el rocódromo o bien marcándola en el propio ordenador.

Es importante mencionar que, tradicionalmente, para el registro de las variables cinemáticas de los deportistas, como son su posición, velocidad y aceleración en la realización de un recorrido o un gesto deportivo mediante sistemas telemétricos se han venido utilizando equipos informáticos que permiten la digitalización de imágenes de videos grabados para realizar posteriormente un análisis 2D o 3D de los desplazamientos del deportista. Su fundamento es transformar mediante la calibración de un sistema de referencia fijo, las imágenes grabadas con cámaras de alta velocidad del deportista y posteriormente digitalizadas mediante un software específico en coordenadas reales, las cuales nos permitirán calcular el desplazamiento, la velocidad o la aceleración del sujeto y los ángulos de sus distintas articulaciones. Otros sistemas de digitalización de imágenes utilizan reflectores de luz que, colocados en posiciones estratégicas del cuerpo humano, pueden ser reconocidos por un software específico y digitalizados en tiempo real.

Sin embargo, el sistema propuesto no precisa de cámaras de alta velocidad, ni un mono o traje cinemático con los distintos reflectores cosidos en los puntos articulares, sino que son los acelerómetros colocados en posiciones estratégicos del cuerpo del escalador los que van a permitir calcular su desplazamiento, velocidad o trayectoria.

El sistema está compuesto por un conjunto de sensores inerciales, los cuales se localizan, entre otras posiciones posibles, en las muñecas, tobillos y arnés de escalada del deportista; una tableta digitalizadora o dispositivo informático dotado de pantalla táctil, un ordenador personal con un software específico, un sistema de emisión de sonido y un proyector láser.

Los estudios de la Memoria de Trabajo por las neurociencias han mostrado que el ejercicio y los movimientos corporales mediante secuencias estructuradas y las características del contexto mejoran y ejercen un efecto facilitado, lo cual es, sin lugar a duda, una gran ventaja para el trabajo de esta capacidad.

Para ello, la invención propuesta permite el entrenamiento de la técnica en escalada, mediante la visualización por parte del deportista de recorridos ya grabados previamente, captados por medio de los sistemas inerciales o diseñados por medio de la tableta digitalizadora.

El sistema permite además la medición de variables fundamentales en psicología del ejercicio y neurociencias, como tiempos de reacción ante estímulos, ante situaciones estresantes de sonidos o imágenes exteriores, etc.

Por último, es importante mencionar que también permite mejorar la técnica de la escalada mediante la proyección de rutas realizadas previamente por algún escalador experto, de tal forma que le sirva de guía del recorrido, presa donde ha de realizar el agarre, o cualquier otra información técnica o deportiva que le permita una mejora en el rendimiento.

Entre las ventajas que aporta el sistema objeto de la invención respecto del resto de sistemas que forman parte del estado de la técnica se encuentran:

1. No existen en la actualidad rocódromos preparados para el entrenamiento de la Memoria de Trabajo y solo se han observado rocódromos con presas iluminadas con fines estéticos y técnicos pero que no permiten el desarrollo y el entrenamiento de esta capacidad.

2. No existe en la actualidad sistema para el entrenamiento de la escalada que permita el trabajo de factores psicológicos o relacionados con la neurociencia. Destacar la medición de tiempos de reacción o de ejecución ante estímulos estresantes como puede ser la emisión de sonido ambiente, ruido u otros factores que puedan alterar la técnica del deportista.

3. Permite que cualquier rocódromo pueda ser utilizado para la proyección láser de diferentes rutas y modelos anatómicos, de tal forma que se pueda ejercitar la Memoria de Trabajo en diversos escenarios. Mediante la tableta digitalizadora y conociendo la localización de las diferentes presas, es posible representar gráficamente el rocódromo, la localización de cada presa para posteriormente diseñar recorridos alternativos que deberá realizar el escalador. Tales recorridos son proyectados por la luz láser para el entrenamiento físico y técnico del escalador.

4. La localización de sistemas inerciales en diferentes zonas corporales permite que el sistema localice y posteriormente reproduzca la posición de cada presa donde el escalador ha colocado sus manos y pies durante la escalada. Las coordenadas de cada segmento corporal son grabadas por el sistema y permiten su reproducción y proyección sobre el rocódromo por el haz de luz láser, representado al sujeto como un modelo anatómico alámbrico.

5. Permite ser utilizado como herramienta para evaluar y entrenar la Memoria de Trabajo viso /espacial en otros colectivos, como pacientes con daño cerebral adquirido o personas con Trastorno por Déficit de Atención e Hiperactividad.

6. Sistema portátil que puede ser utilizado en cualquier rocódromo, sin necesidad de modificar su estructura o instalar presa iluminadas diferentes a las que ya dispone.

BREVE DESCRIPCIÓN DE LAS FIGURAS

FIGURA 1: Muestra los diferentes componentes del sistema y su ubicación. En ella se distinguen los siguientes componentes:

1. Sensores inerciales.
2. Tableta digitalizadora/dispositivo informático dotado de pantalla táctil.
3. Ordenador personal/Sistema de recepción y adquisición de datos.
4. Sistema emisión de sonidos.
5. Proyector láser.

FIGURA 2: Esquematiza la proyección sobre la pared del rocódromo por medio del proyector láser la imagen obtenida por parte de los sensores inerciales de la posición de cada segmento corporal del escalador.

FIGURA 3: Esquematiza la proyección sobre la pared del rocódromo la imagen de una ruta generada a través de la tableta digitalizadora/dispositivo informático dotado de pantalla táctil proyectada por el proyector láser, para el entrenamiento de la Memoria de Trabajo.

REALIZACIÓN PREFERENTE DE LA INVENCIÓN.

La Sistema autónomo y portable para el entrenamiento de la memoria de trabajo y la técnica en escalada, objeto de la presente invención, comprende los siguientes componentes:

a) Conjunto de sensores inerciales (1): Gracias a estos sensores es posible conocer diferentes variables cinemáticas, como la posición, velocidad y aceleración del segmento corporal donde este se localice. Los sensores inerciales están conectados vía inalámbrica con un ordenador personal/sistema de recepción y adquisición de datos.

Los sensores inerciales (1) deben colocarse en lugares estratégicos del cuerpo del escalador o escaladora, por ejemplo, tobillos, muñecas y arnés, y permite detectar las posiciones de cada segmento corporal.

El número idóneo de estos sensores inerciales es de cinco. Cuatro de los cinco sensores inerciales van a ser localizados en los dos tobillos y en las dos muñecas del deportista y un quinto sensor inercial será colocado en el arnés del escalador.

Para una mayor precisión y detalle del movimiento se podrán incluir otros tantos sensores inerciales como se considere oportuno.

Los datos captados por estos sensores son transmitidos de forma inalámbrica a un ordenador personal/sistema de recepción y adquisición de datos (3) para su tratamiento y así calcular variables cinemáticas y registro de rutas y entrenamientos.

b) Tableta digitalizadora/dispositivo informático dotado de pantalla táctil (2): Este dispositivo incorpora el software necesario para introducir los datos sobre posicionamiento de cada presa del rocódromo, creando una imagen virtual del mismo y de la posición de cada agarre y además, y lo más importante, permite el diseño de marcas, imágenes, recorridos, etc., que permiten el diseño de rutas de escalada o marcado de presas, para su envío al ordenador personal/sistema de recepción y adquisición de datos.

c) Ordenador personal/Sistema de recepción y adquisición de datos (3): Dotado de un software específico que:

- Recibe y almacena los datos de posicionamiento de los sensores inerciales (1), que describen el desplazamiento realizado por un escalador en el rocódromo y realiza el tratamiento y análisis de la señal recibida.
- Recibe y almacena la información de las rutas generadas manualmente en la tableta digitalizadora/dispositivo informático dotado de pantalla táctil (2).
- Proyecta la ruta, ya sea generada a partir de los datos captados por los sensores inerciales (1) colocados en el cuerpo un escalador que realiza previamente una ruta, o bien por su introducción manual, a través de una tableta digitalizadora/dispositivo informático dotado de pantalla táctil (2) por parte del entrenador o usuario, tanto en su pantalla como a través del proyector láser (5), durante un tiempo determinado, durante el cual el escalador deberá memorizarla, para posteriormente ejecutarla escalando sobre el rocódromo, o reproducirla sobre el ordenador.

d) Sistema de emisión de sonido (4): Compuesto por uno o más altavoces que emiten señales acústicas o instrucciones al escalador. Las señales acústicas pueden ser programadas por el usuario para el inicio del entrenamiento de la Memoria de Trabajo, emitir señales de inicio / fin de los tests, emitir sonidos para trabajos en situaciones de stress o emitir instrucciones por parte del entrenador.

e) Proyector láser (5): El proyector láser (5) colocado a cierta distancia del rocódromo proyecta un haz de luz láser que recrea sobre el rocódromo el modelo anatómico definido por los datos captados por los sensores inerciales (1) colocados en el cuerpo del escalador o bien los diseños, rutas, marcas, etc., que por medio de la tableta digitalizadora/dispositivo informático dotado de pantalla táctil (2) han sido creados por el usuario.

El sistema permite entrenar la memoria de trabajo de varias formas, siendo las más representativas las siguientes:

a) El usuario, por medio de la tableta digitalizadora (2) y mediante un software específico, marca o diseña un recorrido de presas. Dicho diseño será proyectado sobre el rocódromo por medio del proyector de láser (5) durante un tiempo determinado, durante el cual el escalador lo deberá memorizar. Posteriormente el escalador lo deberá ejecutar escalando sobre el rocódromo o reproducir en el ordenador personal (3). Durante el proceso, señales acústicas marcarán los tiempos de inicio o de fin. Otro tipo de test o información para el trabajo de otros sistemas de Memoria o procesos cognitivos pueden ser diseñados y proyectados.

b) El escalador una vez preparado con los sensores inerciales (1) colocados en los puntos anatómicos, elegidos según preferencias del usuario, se posiciona en el punto de inicio de la vía en el rocódromo. Dichos sensores inerciales (1) son reseteados o puestos a cero para iniciar la emisión de los valores de posición, velocidad y aceleración de cada uno de ellos. A partir de este momento el escalador inicia la ruta y en tiempo real son emitidos los datos de cada sensor inercial y grabados por la unidad de control (3). Un software específico se encarga del tratamiento y análisis de datos en tiempo real. Señales acústicas permiten marcar tiempos de inicio o de fin.

c) A partir de los datos de posición, velocidad y aceleración es posible obtener el perfil de condición física del escalador y la ruta realizada. De igual forma, dicha ruta y trayectoria será utilizada para el diseño de tareas y ejercicios para el entrenamiento de la Memoria de trabajo, la cual requiere, de igual forma de un software específico. Las variables obtenidas, como es la aceleración y desplazamiento vertical, nos permitirá, junto el conocimiento de la masa del escalador, calcular la fuerza y el trabajo desarrollado. Otras variables y cálculos cinemáticos y dinámicos son también posibles.

MANERA EN QUE LA INVENCIÓN ES SUSCEPTIBLE DE APLICACIÓN INDUSTRIAL

No se considera necesario hacer más extensa esta descripción para que cualquier experto en la materia comprenda el alcance de la invención y las ventajas que de la misma se derivan.

Los materiales, forma, tamaño y disposición de los elementos serán susceptibles de variación, siempre y cuando ello no suponga una alteración a la esencialidad del invento.

Los términos en que se ha descrito esta memoria deberán ser tomados siempre con carácter amplio y no limitativo.

REIVINDICACIONES

1. Sistema autónomo y portable para el entrenamiento de la memoria de trabajo y la técnica en escalada, basado en la reproducción de rutas o trayectorias sobre un rocódromo cualquiera, sobre el que no es necesario realizar ninguna adaptación, caracterizado por que sobre dicho rocódromo, se proyecta una imagen generada por un proyector láser (5), acompañada de la emisión de estímulos auditivos (4), durante un tiempo determinado, correspondiente a una ruta o trayectoria, que tras un tiempo de observación, deberá ser reproducida por el escalador, que comprende:
   a) Un conjunto de sensores inerciales (1), que proporcionan variables cinemáticas, como la posición, velocidad y aceleración del segmento corporal del usuario donde este se localice, los cuales están conectados vía inalámbrica con un ordenador personal/sistema de recepción y adquisición de datos (3).
   b) Una tableta digitalizadora/dispositivo informático dotado de pantalla táctil (2), que incorpora software necesario para introducir datos sobre el posicionamiento de cada presa del rocódromo, creando una imagen virtual del mismo y de la posición de cada agarre y diseñar las rutas de escalada o marcado de presas, para su envío al ordenador personal/sistema de recepción y adquisición de datos (3).
   c) Ordenador personal/Sistema de recepción y adquisición de datos (3), que incorpora el software necesario para:

      - Recibir y almacenar los datos de posicionamiento de los sensores inerciales (1), que describen el desplazamiento realizado por un escalador en el rocódromo y realiza el tratamiento y análisis de la señal recibida.

      - Recibir y almacenar la información de las rutas generadas manualmente en la tableta digitalizadora/dispositivo informático dotado de pantalla táctil (2).

      - Proyectar la ruta, ya sea generada a partir de los datos captados por los sensores inerciales (1) colocados en el cuerpo un escalador que realiza previamente una ruta, o bien por su introducción manual, a través de una tableta digitalizadora/dispositivo informático dotado de pantalla táctil (2) por parte del entrenador o usuario, tanto en su pantalla como a través del proyector láser (5), durante un tiempo determinado, durante el cual el escalador deberá memorizarla, para posteriormente ejecutarla escalando sobre el rocódromo, o reproducirla sobre el ordenador.

d) Sistema de emisión de sonido (4): Compuesto por uno o más altavoces que emiten señales acústicas o instrucciones al escalador, las cuales pueden ser programadas por el usuario.

e) Proyector láser (5): El cual, colocado a cierta distancia del rocódromo proyecta un haz de luz láser que recrea sobre este el modelo anatómico definido por los datos captados por los sensores inerciales (1) colocados en el cuerpo del escalador o bien los diseños, rutas, marcas, etc., que por medio de la tableta digitalizadora/dispositivo informático dotado de pantalla táctil (2) han sido creados por el usuario.

FIGURA 1

ES 1 302 081 U

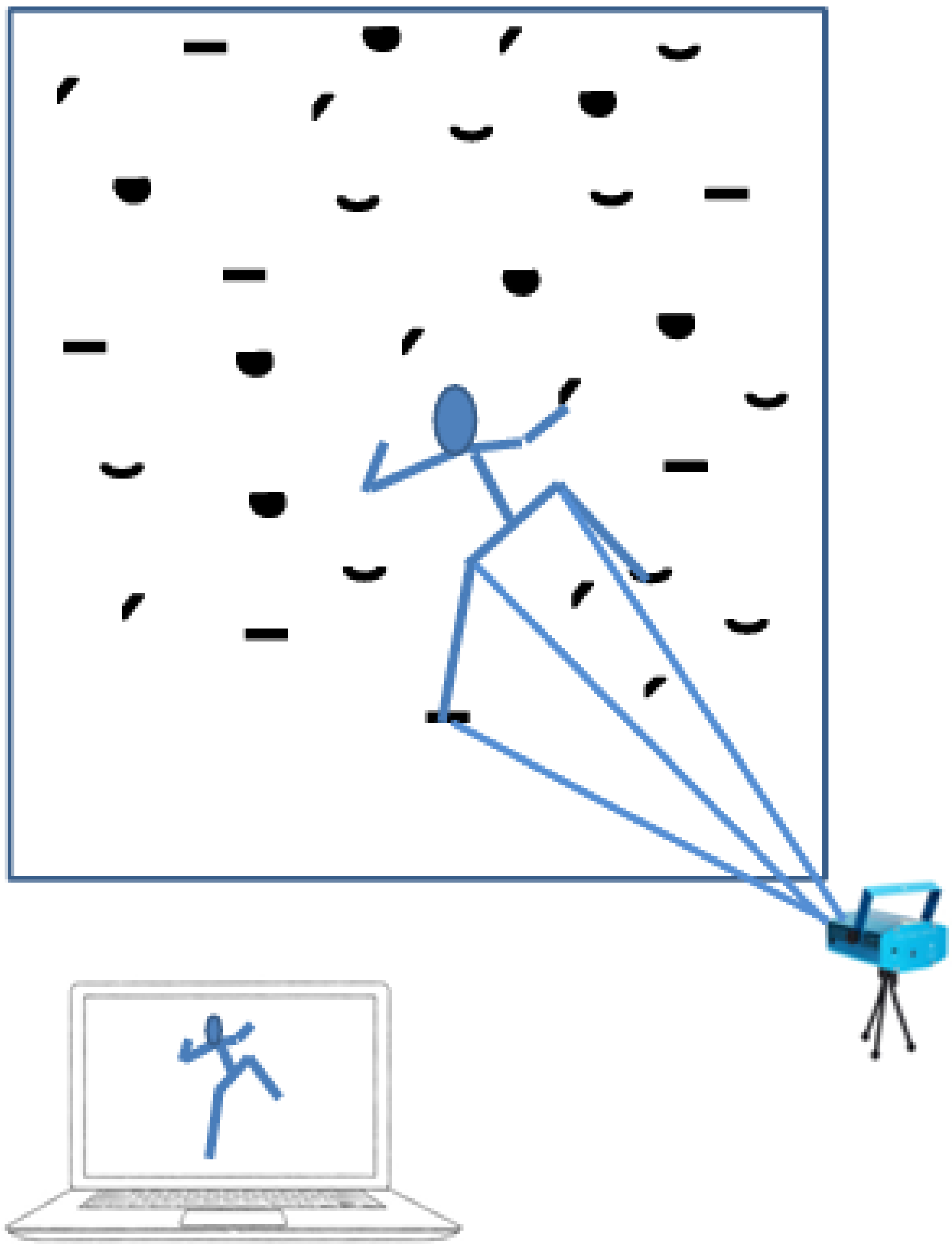

FIGURA 2

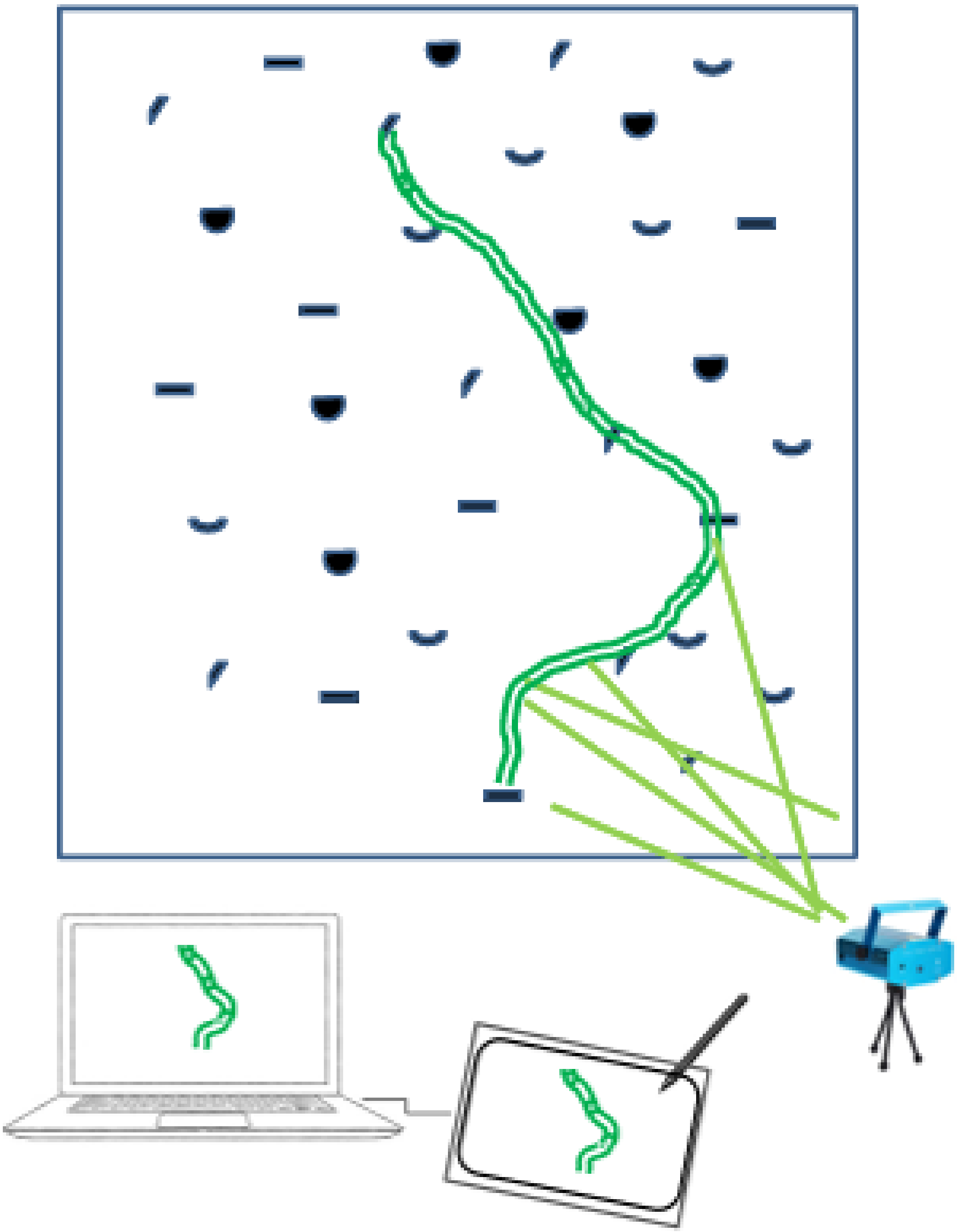

FIGURA 3

ANNEX IV. ROLE OF EMOTIONAL INTELLIGENCE ON ROCK CLIMBING PERFORMANCE.

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Role of emotional intelligence on rock climbing performance
El rol de la inteligencia emocional en el rendimiento en escalada

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Abstract

Purpose: To investigate the association between emotional intelligence (EI) and self-reported climbing ability. Methods: Redpoint climbing ability was used as an indicator of rock climbing performance and EI were assessed as ability and a trait using two different questionnaires MSCEIT and SSEIT in forty-three climbers (15 females and 28 males). ANOVA was used to analyse differences between male and female and advanced and elite climbers in EI parameters in both questionnaires. The analyses were also adjusted by age using ANCOVA. Results: Linear regression analysis revealed that there are no differences between trait EI and climbing performance, but we found the component `Facilitation Thought' of EI measured as ability was inversely associated with the highest red-point ability. Conclusion: Our results suggest that elite climbers do not use their emotions to facilitate thinking as much as expert climbers, which is positively related to performance. Future researches should direct to investigate how elite climbers manage their emotions.

Key words: MSCEIT; SSEIT; emotions; trait; climbing ability.

Resumen

Objetivo: Investigar la asociación entre la inteligencia emocional (IE) y el nivel de escalada autoinformada. Método: Se usó el nivel de escalada ensayado como un indicador del rendimiento de la escalada en roca y se evaluó en cuarenta y tres escaladores (15 mujeres y 28 hombres) la IE como habilidad tanto como rasgo, utilizando dos cuestionarios diferentes MSCEIT y SSEIT. Se utilizó un ANOVA para analizar las diferencias entre los escaladores masculinos y femeninos y avanzados y élite en los parámetros de IE en ambos cuestionarios. Los análisis también se ajustaron por edad utilizando un ANCOVA. Resultados: El análisis de regresión lineal reveló que no hay diferencias entre el rasgo IE y el rendimiento en escalada, pero encontramos que el componente´facilitación del pensamiento´ de IE como habilidad estaba inversamente asociado con un mayor nivel de escalada ensayada. Conclusión: Nuestros resultados sugieren que los escaladores de élite no usan sus emociones para facilitar el pensamiento, en relación con los escaladores expertos, lo que se relaciona positivamente con el rendimiento. Las investigaciones futuras deben dirigirse a investigar cómo los escaladores de élite manejan sus emociones.

Palabras clave: MSCEIT; SSEIT; emociones; rasgo; nivel de habilidad de escalada.

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Introduction

Sport climbing is a complex sport, with success determined by a combination of technical, physical and psychological characteristics (España-Romero et al., 2009; Watts, 2004). As such, due to the sports multifaceted nature, examining the individual contribution of physiological and psychological determinants to sport climbing performance is challenging. Much of the previous literature has focused on physiological mechanisms, and determinants of sport climbing (España Romero et al., 2009; España-Romero et al., 2009; España-Romero et al., 2012; Watts, 2004). Although success or failure in sport rock climbing has been suggested to rely heavily on the psychological state of the performer, there remains a dearth of research investigating these demands, particularly cognitive behaviour (Aras & Akalan, 2014; Bourdin, Teasdale, & Nougier, 1998; Green & Helton, 2011; Hardy & Jackson, 1996; Hodgson et al., 2009; Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008).

In climbing performance context, the psychological characteristics that might contribute to sport climbing success have been studied (Aşçi, Demirhan, & Dinç, 2007; Pijpers, J., Oudejans, R. R., Bakker, F. C., & Beek, 2006; Pijpers, Oudejans, & Bakker, 2005; Sanchez, Boschker, & Llewellyn, 2010; Sarrazin, Roberts, Cury, Biddle, & Famose, 2002). Aşçi et al., (2007) suggested that psychological characteristics such as sensation seeking, physical self-perception and extrinsic-intrinsic motivation of climbers were not related to the difficulty of routes ascended by climbers. However, literature points out other psychological variables that might be related to climbing performance. These variables are achievement goals, perceived ability (Sarrazin et al., 2002) and anxiety (Pijpers et al. 2006; Pijpers, Oudejans, & Bakker, 2005; Sanchez, Boschker, & Llewellyn, 2010). Nevertheless, not all of those psychological variables seem to affect in the same way. Specifically, task focused achievement goals and perceived ability seemed to have a positive relationship with climbing performance while that ego focused achievement goals and anxiety were reported as disrupt in the climbers' performance. Among those variables, the effect of anxiety on climbing performance has been specially studied. This effect is evidenced by increases both in climbing time (Pijpers et al., 2005; Sanchez et al., 2010) and the number of exploratory movements, as well as longer time periods holding handholds, and slower movements (Pijpers et al., 2005). Conversely, anxiety may play a different role for some climbers producing an improvement in performance, as suggested by the theory of information processing efficiency (Calvo & Eysenck, 1992). Thus, Hardy & Hutchinson, (2007) reported that increased anxiety may be associated with increased effort and improved or sustained performance. Further, Sanchez et al., (2010) reported that pre-performance somatic anxiety could be a trait that provides elite climbers with superior performance, and not one that is detrimental.

Emotions, like anxiety, are present in sport climbing, affecting individual performance and ultimately success and failure (Robazza, Bortoli, & Nougier, 1998). In sport psychology, the concept of emotional intelligence (EI), proposed by Salovey & Mayer, (1990), could explain the process through which people recognise which emotions appear to help performance and which emotions might hinder performance. Although the ability of athletes to recognise, control and manage their emotions during sport climbing may influence sport climbing performance, it has not been examined yet. In mainstream sports such as baseball and cricket, studies have observed a relationship between EI and performance (Crombie et al., 2009; Zizzi, Deaner, & Hirschhorn, 2003). Therefore, if the EI of sport rock climbers is related to performance, then it could be that it is an important psychological component, which could be integrated into training programs in order to enhance overall performance. As such, the aim of the study was to examine EI in a range of different ability sport rock climbers.

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Methods

Participants

Forty-three experienced sport climbers (15 female and 28 males) aged 18 - 44 years old from Spain volunteered to participate. Climbing experience (yrs), frequency of climbing practice (days per week) and self-reported climbing ability (in accordance with Draper et al., (2011) are presented in Table 1 by gender and climbing ability.

Climbing ability was reported by the most difficult route completed without falls, without inspection or prior knowledge (called onsight climbing) and the most difficult route ascended (without fall or weighting the rope) after having had practice of the route (called redpoint climbing).

Following a comprehensive verbal description of the nature and purpose of the study, written informed consent was obtained. The study protocol was performed in accordance with the ethical standards established in the 1961 declaration of Helsinki and was approved by the Research Ethics Committee from our University.

Table 1. *Descriptive Characteristics of the Study Sample*

	Male (n=28)	Female (n=14)	Expert (n=27)	Elite (n=15)
Age (yrs)	32.8 ± 6.6	38.0 ± 3.6**	33.8 ± 6.9	35.3 ± 5.4
Weight (kg)	68.2 ± 6.5	55.2 ± 5.0**††	64.8 ± 8.9	62.2 ± 7.7
Height (cm)	173.7 ± 7.6	164.8 ± 4.7**††	171.4 ± 8.0	169.5 ± 7.8
Climbing experience (yrs)	11.2 ± 7.5	11.7 ± 5.9††	10.3 ± 6.2	12.8 ± 8.5††
Climbing frequency (days per week)	3.6 ± 1.3	2.8 ± 1.0	3.2 ± 1.2	3.7 ± 1.3
Onsight climbing performance	2.6 ± 0.7	2.0 ± 0.5*†	2.0 ± 0.4	3.2 ± 0.5**††
Redpoint climbing performance	7a+	6c*†	6c	7c**††

** P< 0.001 and *P<0.05 differences between male and female or expert and elite climbers group

††P<0.001 and † P<0.05 differences between male and female or expert and elite climbers adjusted by age

Emotional Intelligence measurements

Emotional Intelligence was measured by two different scales, the Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT) (Mayer, Salovey, Caruso, & Sitarenios, 2003), measuring EI as an ability; and the Schutte Self Report Emotional Intelligence Test (SSEIT) (Schutte et al., 1998) measuring EI as a trait.

The MSCEIT is an ability-based measure that uses two areas (Experimental and strategic EI) to assess each of the four factors of EI (Perceiving and Identifying, Using, Understanding, and Managing Emotions). The questionnaire is made up by 141 items according to the theoretical

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model of Mayer and Salovey, (1997). Separate scores for each factor are provided, as well as an overall score for total EI; scores can be calculated based on expert or consensus criteria. In the present study, we used consensus criteria to calculate scores for each of the four factors and total EI. Scores are standardized (*M* = 100, *SD* = 15). MSCEIT usually takes approximately 45-60 minutes to be completed. Reliability analyses of the MSCEIT with the standardisation sample suggested that the questionnaire has good internal consistency at the full-scale, area and factor level (Mayer, et al., 2003).

The SSEIT is a trait-based measure that evaluates how individuals are able to identify, understand and regulate emotions themselves and in others. The questionnaire is made up by 33 items that they should be answered by a Likert scale from 1 to 5 where 1 is strongly agree and 5 strongly disagree. SSEIT usually takes approximately 15-20 minutes to be completed. Reliability analyses of the SSEIT suggested that the questionnaire has good internal reliability, indicating that the scores were fairly stable over time (Schutte et al., 1998).

Climbing ability performance

Self-reported climbing ability was reported as the most difficult red-point (pre-practised) route completed without falls within the last 6-12 months. This method has been previously validated by (Draper et al., 2011). Climbing ability was converted to a standard numerical scale to enable calculations and statistical analyses according to (Draper et al., 2016). The sex-specific 75th percentile of red-point climbing ability was used to divide the sample into advanced (≥75th) and elite (<75th) climbers for further analyses following the rationale of España-Romero et al., 2009.

Data analysis

All the variables showed a satisfactory pattern after studying their distribution using the Kolmogorov–Smirnov's test. The data are presented as mean and standard deviation (SD). Differences between male and female as well as expert and elite climbers in EI parameters in both questionnaires were analysed by one-way analysis of variance. The analyses were also adjusted by age using one-way analyses of co-variance (ANCOVA). Linear regression analyses were performed to examine the relationship between EI and gender as well as EI and climbing performance. Statistical analyses were performed using STATA version 14.0 (Stata Corp, College Station, TX, USA). Statistical significance was set at $p < 0.05$.

Results

Red-point climbing ability in women ranged from 6c to 7a in advanced climbers (n = 9), and from 7a+ to 7c in elite climbers (75th percentile, 7a+, n = 6). In men, climbing ability ranged from 6b to 7c in advanced climbers (n = 20), and from 7c+ to 8b+ in the elite group (75th percentile, 7c+, n = 8).

MSCEIT scores are presented in Table 2. Significant differences were found for `Facilitation Thought´, Advanced climbers had a significantly higher measure of `Facilitation Thought´ compared to Elite climbers (110.4 ± 10.6 vs. 102.9 ± 11.8, respectively). The same results were found when analyses were performed adjusted by age.

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Table 2. *MSCEIT Scores Split by Sex and Climbing Ability*

	Male (n=28)	Female (n=14)	Expert (n=27)	Elite (n=15)
Total score MSCEIT	103.4 ± 10.5	107.5 ± 10.4	105.1 ± 10.0	104.4 ± 11.8
Areas				
Experiential area	104.3 ± 11.0	108.5 ± 12.5	107.1 ± 11.8	103.2 ± 11.2
Strategic area	101.7 ± 11.5	104.1 ± 8.0	101.8 ± 9.9	103.9 ± 11.7
Aptitudes				
Perceiving Emotions	101.8 ± 13.5	107.6 ± 14.1	104.4 ± 15.1	102.6 ± 11.5
Facilitation Thought	107.7 ± 11.0	107.5 ± 12.7	110.4 ± 10.6	102.9 ±11.8*†
Understanding Emotions	96.9 ± 11.9	96.9 ± 7.6	95.7 ± 10.6	99.1 ± 10.7
Managing Emotions	107.5 ± 10.4	113.3 ± 11.8	110.0 ± 10.7	108.6 ± 12.3

MSCEIT scores measured by the Mayer-Salovey-Caruso Emotional Intelligence Test.

* P< 0.05 differences between male and female or expert and elite climbers

† P<0.05 differences between male and female or expert and elite climbers adjusted by age

SSEIT scores are presented in Table 3. Skill 'Expression of Emotions' and 'Regulation of Emotions' were significantly higher in males than females (55.6 ± 5.2 and 43.4 ± 3.5, respectively), however, the significance disappeared when adjusted for age.

Table 3. *SSEIT Scores Split by Sex and Climbing Ability*

	Male (n=27)	Female (n=14)	Expert (n=26)	Elite (n=15)
Total score SSEIT	131.2 ± 10.8	126.4 ± 11.1	131.1 ± 11.2	126.7 ± 10.4
Expression of emotions	55.6 ± 5.2*	52.2 ± 4.4	55.6 ± 5.3	52.4 ± 4.4
Regulation of emotions	43.4 ± 3.5*	40.7 ± 4.2	42.8 ± 4.1	42.0 ± 3.5
Use of emotions	32.0 ± 4.3	33.4 ± 3.8	32.6 ± 3.3	32.2 ± 5.4

Linear regression analyses adjusted for age revealed that `Facilitation Thought´ was inversely associated with the highest red-point ability (β:-7.04 and 95% CI: -14.19 to -0.10; $p < 0.05$). The percentage of variance (R^2) explained by self-reported grade was 14.5% (Figure 1).

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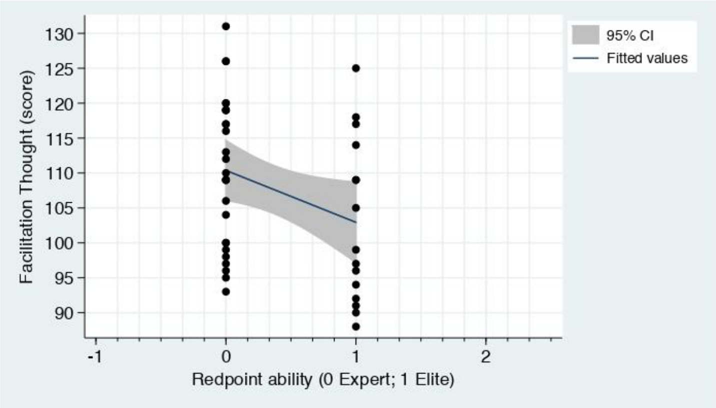

Figure 1. Linear regression analyses between `Facilitation Thought´ and redpoint ability categories adjusted by age

Discussion

Some authors speculate that EI could influence in athletes because they are better able to perceive, monitor, use, and manage emotions in response to competition stress and use more effective coping strategies in response to the emotions (Crombie et al., 2009; Zizzi et al., 2003). This position supports the idea that higher levels of EI could help to reach higher levels of sport performance.

Given emotions could have negative effects in sport climbing (Green, Draper & Helton, 2014), we might think that EI had a relationship with climbing performance. The main finding of this study was that elite climbers presented lower scores compared to advanced climbers for an EI component, i.e., *`Facilitation Thought´*, when it was assessed by the MSCEIT questionnaire. Differences between EI and climbing performance were not observed when EI was assessed using the SSEIT questionnaire. While literature on emotional intelligence argues the use of emotions as a facilitator to improve sports performance, since participants could take advantage of these emotions in the use of certain cognitive practices, such as reasoning, problem-solving, decision making and interpersonal communication (Brackett & Salovey, 2006), we observed contrary results in sport climbers. Therefore, the results observed in this study show that high and low EI scores may differentiate ability groups of climbers and may be an important factor for climbing performance. However, it is necessary to understand those differences in our results are likely due to different approaches of emotional intelligence, since ability approach of emotional intelligence, assessed by MSCEIT questionnaire, which is a range that could be modify by training. Whereas trait approach of emotional intelligence, measured by SSEIT, which are aspects of personality that are relatively stable over time.

The current study suggests that the ability construct *`Facilitation Thought´* is related to climbing performance. Although we hypothesized a priori that elite climbers would exhibit higher emotional intelligence scores, the differences were in the opposite direction to what we expected. The relationship observed between *`Facilitation Thought´* and sport performance could suggest that higher scores in this component could be a disadvantage to climbing performance. In an effort to understand the observed negative relationship between *`Facilitation Thought´* and climbing performance, a number of reasons may be offered to explain why elite climbers have a lower EI score, and why this may be advantageous.

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`Facilitation Thought´ refers how emotions may be used in different situations and how they may be associated with sensations to facilitating of thought and then allowing emotions to direct attention. In sport psychology, anxiety is generally accepted as an unpleasant emotion likely to arise when individuals doubt their ability to cope with external or internal demands (Woodman & Hardy, 2003). Anxiety has an important presence in sport climbing and it has been observed that detrimentally affect performance in climbers (Green et al., 2014; Nieuwenhuys et al., 2008; Pijpers et al., 2005). However, it is possible that climbers with higher levels of *`Facilitation Thought´* could perceive an increase in anxiety, caused by emotions present in sport climbing as fear or threat. As a result of this fear or threat, there may be a disruption in performance which may occur as a result of either attention being focused on the emotions rather than the task (distraction), and/or conscious monitoring of the movement and technique (conscious processing) (Nieuwenhuys & Oudejans, 2012).

Another potential reason for performance disruption may be that climbers with higher levels of *`Facilitation Thought´* are more susceptible to experiencing negative emotions because of the characteristics of the demands of rock climbing. For example, the distance between points of protection on a route, a fear of failure or a fear of falling (Draper et al., 2012; Draper, Jones, Fryer, Hodgson, & Blackwell, 2010; Draper, Jones, Fryer, Hodgson, & Blackwell, 2008). Additionally, *`Facilitation Thought´* could facilitate an attention focus on emotions by causing cognitive interference within the climber (McCarthy, Allen, & Jones, 2013) or by consuming cognitive resources necessary for motor planning or by altering the climber's focus of attention (Green et al., 2014). This would mean they become distracted by the anguish generated by different types of fear (fear of failure or fear of falling) causing decrements in performance on tasks, according to Green et al. (2014). Therefore, it could be possible that a low score on these components of EI, allows elite rock climbers not to interact with those emotions, that negatively interfering with their limited attentional resources. Additionally, we suggest it could be possible that elite climbers had attentional superiority on skill-related rock climbing, that prevent negative emotional interferences that act as a strong distractor as expose He et al. (2018) in a EEG research with tennis players .

The current study is the first known investigation, which analyses EI as an ability and as a trait in a non-group/team based sport. Previously, while EI as trait has also been assessed in individual athletes (Chakarvarti & Lal, 2016) to our knowledge EI has only been measured as an ability in team sports (Crombie et al., 2009; Crombie et al., 2011; Laborde et al., 2015). When assessed as a trait using the SSEIT, Chakarvarti & Lal, (2016) observed contradictory results to ours, with significant differences for EI, as a trait, in 15 individual athletes categorized at the high-performance group compared to the 8 athletes categorised at the low performance group. The differences in our results could be attributed to different sporting contexts, demands or performances promote the development of different psychological skills or cognitive-emotional functioning (sprinters against climbers) (Schmidt & Wrisberg, 2008). As suggested by Taylor, (1995) each sport has special physical, technical and psychological characteristics which requires specific mental abilities for its practicing athletes, what can make sense of these differences in our results.

Although various authors have repeatedly suggested that variables of a psychological nature may be crucial to successful climbing performance (Espana-Romero et al., 2012; Watts, 2004), this study is the first study exploring the relationship between EI and climbing performance and the first with ability measures in an individual sport. Whilst this was the first study of its type in rock climbers, and there are several strengths such as 1) unique access to a highly skilled group of elite climbers, and 2) we used two types' questionnaires to determine EI, there are some limitations that should be recognised. The main limitation concerns the

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sample size. Although the experiment offers statistically significant results, the sample size is small, which causes the study to have low statistical power (53.2%). Moreover, the unresolved issues related the controversy in the construct of EI have implications for researchers and those in professional practice seeking to understand its influence on sports performance (Laborde et al., 2015). Future research should look to examine possible presence or interactions between EI and other variables that may influence climbing performance such as positive affect (Sanchez et al., 2010), self-confidence (Woodman & Hardy, 2003) or attentional resources (Sanchez-Lopez, Silva-Pereyra, & Fernandez, 2016; Taylor, 1995).

Conclusion

In conclusion, the results of this study suggest that elite climbers have lower ability EI component score of *`Facilitation Thought´* compared to advanced climbers when measured as ability but not trait-based measure. These suggest that there is an ability related with the use of emotions to facilitating thoughts linked with differences in climbing performance; further the results imply differences in emotional functioning advantageous for the greatest ability climbers. Rock climbers and coaches should develop a specific training in mental toughness or psychological skills direct to regulating and managing emotions in less experienced climbers. Our findings highlight the needed to consider the influence of other psychological factors upon sport climbing performance that differentiates between elite and expert climbers. Future research should be direct to investigate how emotions affect experts and elite climbers, and how emotions are managed by both types of climbers.

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ANNEX V. FEAR OF FALLING IN WOMEN: A PSYCHOLOGICAL TRAINING INTERVENTION IMPROVES CLIMBING PERFORMANCE

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SPORT AND EXERCISE PSYCHOLOGY

Fear of falling in women: A psychological training intervention improves climbing performance

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ABSTRACT

The main purpose of this study was to determine the effect of a psychological training intervention based on emotional regulation on anxiety and climbing ability in women climbers with fear of falling. A secondary aim was to compare the outcomes of climbing ability, anxiety, self-confidence and interoceptive awareness (IA) between the psychological group (PG), a training (TG) and a control group. Self-reported climbing ability, anxiety and IA were assessed using Competitive State Anxiety Inventory-2 and the Multidimensional Assessment of Interoceptive Awareness questionnaire. Results indicated a significant improvement in climbing ability for both PG and TG. The PG showed a significant reduction in cognitive and somatic anxiety, while the TG only exhibited a reduction in cognitive anxiety. Moreover, the PG demonstrated a greater significant increase in self-confidence compared to the TG. IA improved in five subscales for the PG, whereas the TG changed in only two subscales. In conclusion, a psychological training intervention focusing on emotional regulation might contribute to improvements in IA, reduced anxiety levels, and enhancements in climbing ability and self-confidence among women climbers facing fear of falling.

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Fear of falling; interoceptive awareness; climbing; emotional regulation; psychological training

Introduction

Fear is considered a primary emotion with a protective function generated as a response to a real or perceived imminent threat (Steimer, 2002). By contrast, anxiety represents a state heightened reactivity to threat uncertainty (in the absence of an immediate threat) characterised by high arousal, hypervigilance, deficient safety learning, behavioural and cognitive avoidance (Grupe & Nitschke, 2013). Anxiety and fear can elicit adaptative behavioural responses such fight-or-flight and immobilisation or freezing directed to avoid or reduce a real or perceived harm (Janak & Tye, 2015).

In sport climbing, fear of falling is considered by the scientific community as an element of psychological stress that impairs the performance of climbers (Baláš et al., 2017; Draper et al., 2008; Epling et al., 2018; Giles et al., 2014; Michael et al., 2019; Pijpers et al., 2003). This fear is often associated with learned and adaptive behaviours (Gajdošík et al., 2020; LeDoux, 2014), that could be directed to avoid a real or perceived threat of a climbing situation. For instance, the height above the ground, without taking into account the climbing safety gear, seems to induce stress in lower grade and intermediate climbers, but not in advanced climbers (Gajdošík et al., 2020).

Detrimental effects on climbing performance as consequence of fear of falling seem to be associated with a high level of anxiety (Draper et al., 2008, 2012). The most demanding and challenging style affected by anxiety seems to be on-sight lead climbing, compared to red-point (Draper et al., 2012) and top-rope (Aras & Akalan, 2014; Limonta et al., 2020) climbing condition. On-sight lead climbing involves ascending a route with no prior knowledge, attempting it on the first try without previous falls. In this scenario, climbers secure themselves with a rope as they progress, utilising existing wall bolts. Falls are absorbed by the rope and previously passed anchors. Red-point lead climbing entails multiple attempts (typically 3 to 5) until successful completion without falls. Unlike lead conditions, in top-rope climbing, climbers are safeguarded by a rope anchored at the route's top, eliminating the risk of falling (Giles et al., 2014). Therefore, considering the characteristics of the climbing styles, authors argue that heightened anxiety in on-sight climbing arises from the fear of falling due to the lack of a secure top rope and familiarity with the route (Aras & Akalan, 2014; Draper et al., 2008; Limonta et al., 2020). Furthermore, previous literature suggests that female athletes often exhibit higher levels of anxiety compared to their males counterparts (Correia & Rosado, 2019; Rice et al., 2019). Likewise, anxiety derived from lead climbing might affect males and females differently (Villavicencio et al., 2021).

Regarding the impact of anxiety on climbing performance, researchers have reported several negative effects, such as a disproportionate rise in heart rate (Aras & Akalan, 2014; Williams et al., 1978), greater perceived effort (Hardy & Hutchinson, 2007; Pijpers et al., 2006), and impaired attentional control (Pijpers et al., 2006). Based on this evidence, some authors have suggested the need for climbers to receive psychological support in order to cope with anxiety (Aras & Akalan,

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2014). However, interventions to reduce anxiety in climbing are limited. Specifically, Maynard et al., (1997) found that a 12-weeks relaxation intervention reduced somatic anxiety during climbing among a group of 30 men but did not significantly improve cognitive anxiety and self-confidence. Similarly, Aras and Ewert (2016) demonstrated significant reductions in somatic and cognitive anxiety, along with an improvement in self-confidence, following an eight weeks top-rope climbing training programme for a group of 19 men. However, both studies were conducted solely with men without prior climbing experience, and did not include an assessment of improvement in climbing performance.

The scientific literature suggests that effective anxiety management is closely related to emotional regulation (Amstadter, 2008; Hanin, 2010; Sakiris & Berle, 2019). Furthermore, researchers also highlight the importance of interoceptive awareness (IA) as a crucial component for successful emotional regulation and anxiety control (Barlow et al., 2017), as recently reported in the context of athletes (DiFronso et al., 2022). IA refers to the awareness of bodily signals derived from emotions, contributing to emotional experience (Füstös et al., 2013; Mehling et al., 2009). This interoceptive information is considered essential for homoeostatic control and enables individuals recognise and understand emotions, thus facilitating emotion regulation and the development of coping strategies in response to stressors (Price & Hooven, 2018). Within this framework, difficulties in recognising interoceptive information characterise anxiety dysregulation (Critchley & Garfinkel, 2017a). However, to the best of our knowledge, no research has yet investigated whether improving emotional regulation by attending to interoceptive information to cope with falling anxiety leads to improved climbing performance.

Given the limited research concerning experienced climbers and women, the study aim was to determine the effect of a psychological training intervention based on emotional regulation. Specifically, we intend to examine its effects on anxiety and climbing ability among women climbers with fear of falling. Additionally, the second aim was to compare the outcomes of climbing ability, anxiety, self-confidence and IA between three groups: a psychological training group (PG), a physical training group (TG), and a control group (CG). We hypothesised that climbers who undergo psychological training focused on emotional regulation to cope with the fear of falling would exhibit changes in IA, reduced anxiety and improved climbing ability. Moreover, we anticipated that the impact of psychological training would surpass that of physical training across all measured variables.

Material and methods

Study design

A quasi-experimental design was conducted to examine the impact of a psychological training intervention on anxiety levels and climbing performance in women climbers with a fear of falling. The study used a simple pre- to post-intervention comparison of changes in various scores across three groups. The intervention specifically focused on emotional regulation. The PG was composed of climbers who underwent the psychological training focused on emotional regulation. For comparisons, two additional groups were established and evaluated at two points in time (pre-test and post-test). The TG consisted of climbers who followed an individualised climbing training plan under specialized sport instruction, while the CG was made up of climbers who continued their regular, self-guided climbing routines.

Personal invitations were sent to women climbers, climbing clubs, and social media advertisements were utilised to recruit participants for the sports psychology clinic. Potential participants first underwent an eligibility screening through an online form containing the following question: *Do you feel that fear of falling during lead climbing limits or impairs your performance?*. Inclusion criteria were defined as follows: (1) being biologically a woman, (2) reporting to experience fear of falling during lead climbing, (3) having at least one year of climbing experience, and (4) being capable of on-sight lead climbing. On the contrary, exclusion criteria encompassed: (1) simultaneously participation in another clinical trial, (2) any medical prescription that prohibit climbing, (3) presence of an acute or terminal illness, and (4) currently receiving psychological training for climbing.

Participants

A total of 44 recreational women climbers expressed interest in voluntarily participating in the High-Performance International Rock-Climbing Research (C-HIPPER) study. Out of those 44 individuals, 41 met the inclusion criteria and provided informed consent to take part in the study. The participants were subsequently assigned to the three groups according to their background and preferences. The PG consisted of 15 participants who expressed a preference for starting psychological training due to fear of falling and were not undergoing climbing training with a sports specialist. The TG comprised 12 participants who were already following a specialised climbing training programme with a sports specialist. The CG consisted of 14 participants who did not undergo any specific training, either psychological or physical, throughout the study period.

During the course of the study, 10 participants dropped out for personal reasons (seven women) or due to climbing injured (three women). As a result, TG and CG consisted of 10 participants each, while the PG included 11 climbers. Flow chart of participants through the study is shown in Figure 1. Prior to recruitment, the study protocol was approved by the Ethics Committee (PEIBA code 1739-N-21), and data collection was conducted in accordance with the ethical standards set by the journal and, the Declaration of Helsinki.

Procedure

All participants were instructed to continue their regular climbing activities during the study. Pre-test measures of climbing ability, anxiety, self-confidence, and IA were collected after group allocation. The post-test measures were conducted after psychological training intervention for the PG, and four months after recruitment for the TG ad CG. In order to collect appropriate information for the study, participants were instructed to complete the

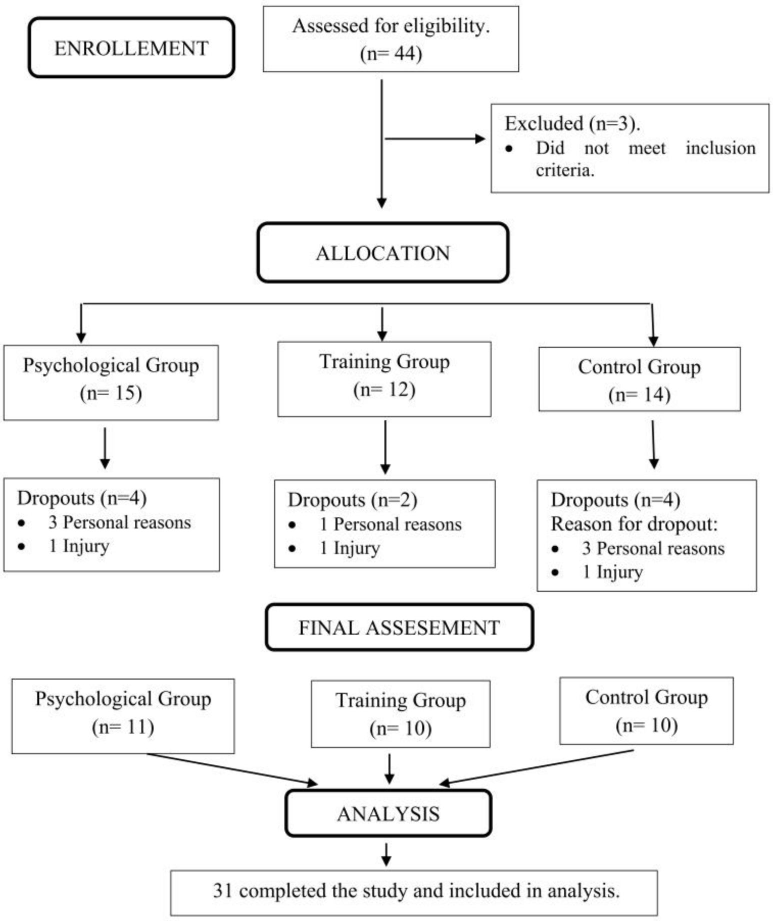

Figure 1. Consort of flowchart of participants.

questionnaires imagining themselves before starting a climbing route. This instruction aimed to capture their state of anxiety and emotional experience in relation to the climbing activity. Additionally, no specific contextual information was provided to anchor their responses, allowing for a more genuine representation of their feelings in the given scenario.

Psychological intervention

The psychological intervention was adapted from Unified Protocol (Sakiris & Berle, 2019), taking into account the principles of sports mental training (Mellalieu & Hanton, 2008) and focused on emotion regulation using IA to cope with anxiety (Füstös et al., 2013; Price & Hooven, 2018). It was conducted by a psychologist registered in accordance with the Spanish law, holding a Master's degree in Sports Psychology, a Master's degree in Neuropsychology, and a specific qualification in the Unified Protocol. Ethical considerations were strictly adhered to throughout the intervention.

The intervention was carried out through a secure and encrypted Internet platform, in accordance with the recommendations of the American Psychological Association (APA) (2013). The intervention comprised three main modules, detailed in Table 1. As described below, each module included theorical sessions lasting 60 minutes, complemented by practical exercises using self-paced worksheets:

a) Awareness Skills Training – The first session entailed psychoeducation about how anxiety works, its main function, and components. Practical exercises focused on identify anxiety components (physical sensations, thoughts, and behaviours) while climbing. – The second session consisted of understanding the role of emotions in climbing, identifying triggering factors and the fear of falling, and learning functional coping strategies developed while climbing. Practical exercises revolved around recognising personal triggers, factors that influence the fear of falling, and coping behaviours while climbing; b) Regulation Skills Training – The first session involved psychoeducation about the influence of fear on body posture, facial expression,

Table 1. Overview of the psychological intervention for fear of falling in climbing.

	Content
Awareness Skills Training	
Anxiety	• Psychoeducation about what is anxiety, cognitive, somatic and behavioural anxiety responses, physical and psychological symptoms and how it affects us. • Identification of different responses associated to anxiety.
Fear and emotions	• Psychoeducation about what is fear, different functions of each emotion, how emotions work and how they manifest. • Identification of emotions. • Identification of different triggers of fear and avoidance behaviours.
Regulation Skills Training	
Emotional regulation Bottom-up	• Psychoeducation about interoceptive awareness (heart rate, breath and arousal) • Identification and understanding of physical sensations related to emotions • Identification body posture and face expression of fear • Identification of breath • Practice of conscious diaphragmatic breathing • HR biofeedback using a pulsometer
Emotional regulation Top-Down	• Psychoeducation about how thoughts can activate or intensify fear and negative emotions • Identification and modification negative and maladaptive thoughts • Identification of different forms of emotional expression • Perception of challenge or threat
Experiential Exposure	
Goal setting	• Identification and readjustment of goals • Establishment of concrete and realistic objectives and development of a specific plan to achieve them • Route previewing • Applying coping skill (reappraisal, self-talk, mindful breathing, challenge instructions, etc.) • Planning and re-planning strategies

and heart rate, and discussed the use of diaphragmatic breathing to modulate heart rate. Practical exercises included: 1) engaging in various activities (e.g., running, pull-ups, different types of climbing: indoor, outdoor, on-sight, red-point climbing, leading, top-rope climbing) to monitor and became familiar with heart rate using a pulsometer, and 2) practicing diaphragmatic breathing to regulate heart rate, monitored by a pulsometer during climbing. The second session covered the impact of thoughts, beliefs, and appraisals on the emotional experience of the fear of falling. Practical exercises focused on identifying and transforming dysfunctional thoughts and beliefs, and establishing functional thinking through self-talk, re-evaluation, and goal setting before and during climbing; c) Experiential Exposure – This involved a single session designed to organise and elucidate the necessary skills and strategies for facing on-sight climbing. Strategies included setting a goal, previewing the route, and establishing an action plan, as well as ensuring proper warm-up. Participants were also instructed to review and adjust their arousal level using breathing exercises and postural readjustments. The use of routines (focus-behaviours) and self-talk was emphasised to aid focus before beginning the climb. Participants were encouraged to use breathing exercises, instructional and motivational self-talk, and focus behaviours during the climb.

Participants were instructed in each session to perform the practical exercises at their own pace, within their climbing context, and guided by specific content worksheets. The information collected across sessions using the worksheets, exemplified in Table 2, was merely noted on an ad-hoc basis. This information was shared at the beginning of each session to refine the intervention for each participant, provide opportunities to ask questions and receive feedback from the sports psychologist. Moreover, participants were asked the same question regarding fear at the outset of each session: *"Do you feel that fear of falling during lead climbing limits or impairs your performance?"*. Since the fear of falling has a multifactorial aetiology (Lee et al., 2018), the intervention was individualised and concluded when participants reported no longer experiencing fear of falling. The total duration of the psychological training intervention was tracked from the first to the last session for each climber.

Measures

Self-reported climbing ability

Climbing ability was assessed by asking each participant about their best on-sight ascent out of more than three route within the last three months. The use of self-reported climbing ability has been validated as an accurate representation of actual climbing ability by Draper et al. (2011), and this method has been widely used in the literature (Baláš et al., 2017; Fryer et al., 2017; Zarattini et al., 2018). For statistical analyses, performance grades were converted from the French Sport scale to the International Rock Climbing Research Association (IRCRA) reporting scale, in accordance with the IRCRA Position Statement (Draper et al., 2016). If a participant reported that they were unable to complete a lead climb, their self-reported ability was recorded as zero.

Anxiety and self-confidence

Anxiety levels and self-confidence were measured using the Spanish version of the Revised Competitive State Anxiety Inventory-2 (CSAI-2 R) (Andrade et al., 2007) adapted from Martens et al. (1990). The scale consists of 16 items that measure three hypothesised dimensions of anxiety: somatic anxiety, cognitive anxiety, and self-confidence. The questionnaire has demonstrated good psychometric properties, including dimensionality and internal consistency, with Cronbach´ alpha values ranging between 0.79 and 0.83 for the different

Table 2. Example of participants´ comments regarding the fear of falling collected across psychological intervention sessions.

Influencing factors in the development and maintenance of the fear of falling	• Previous traumatic experiences or falls • Previous injuries • Falls practice • Difficulties in anxiety regulation • Implicit learning of fear • Overprotective behaviours of the climbing partner • Lack of strength, technique, or climbing abilities • Anxiety sensitivity • Lack of coping skills (problem-focused coping and emotion-focused coping strategies) • Lack of attentional control • Lack of self-confidence • Lack of own goal • Lack of route previewing • Emotional regulation difficulties
Fear of falling triggers	• Route equipment (long distance between bolt) • Rock quality • Social contagion of fear (presence of climbers with fear of falling) • Presence of climbers in the climbing area (social inhibition) • Inexperienced belayer or belayer bad habits • Proprioceptive signal from awkward or unbalanced postures • Lack of warm-up or inadequate warm-up • Lack of adaptation climate (hot, cold or humidity) • Lack of perceptive and decisive skills • Physical and mental fatigue • Difficulties in problem solving and uncertainty management • Excess coffee consumption • Menstrual cycle • Small or slippery foot holds
Avoidance behaviours	• Top-rope climbing • Request always information about the route • Use of stick to clipping • Use quickdraw extension • Leave the climbing route • Avoidance of feared climbing routes

dimensions (Andrade et al., 2007). It has been previously used in climbing research studies (Aras & Akalan, 2014; Aras & Ewert, 2016; Draper et al., 2006, 2012; Fryer et al., 2012; Hodgson et al., 2009; Limonta et al., 2020; Pijpers et al., 2005; Sanchez et al., 2010).

Interoceptive awareness

IA was assessed using the validated and reliable (Valenzuela-Moguillansky & Reyes-Reyes, 2015) Spanish version of the Multidimensional Assessment of Interoceptive Awareness (MAIA) (Mehling et al., 2012). The questionnaire is a self-reported instrument of 32 items rated on a Likert scale, with six levels of ordinal response ranging from 0 (never) to 5 (always). These items are categorised into eight subscales corresponding to different domain of IA: (1) Noticing, (2) Not-Distracting, (3) Not-Worrying, (4) Attention Regulation, (5) Emotional Awareness (6) Self-Regulation, (7) Body Listening and, (8) Trusting. The questionnaire demonstrates good overall internal consistency, with a Cronbach's α of 0.90 for the total scale. The subscale values range from 0.40 to 0.48 for Non-Distracting and Not-Worrying subscales; and from 0.64 to 0.86 for the other different subscales.

Statistical analysis

Normal distributions were ascertained, and homogeneity of variances was confirmed after visual assessment of the frequency histogram, Shapiro – Wilk's and Breusch-Pragan test (Breusch & Pagan, 1979), respectively. All values were reported as means and standard deviations (SD) for continuous variables.

An a priori statistical power analysis was conducted for a sample size of 31 participants using G*Power software (Faul et al., 2007) for the primary outcome measure at baseline. To address potential baseline differences between groups, analysis of covariance (ANCOVAs) were conducted, focusing on variables showing medium to large effects in pre-test ANOVAs. This analysis provided control for potential confounding variables, ensuring a more reliable assessment of the intervention´s impact.

Further analysis involved a repeated measures ANOVA to evaluate the effect of time and the interaction between group factors (Group × Time) on climbing ability, anxiety, self-confidence and IA. The results were reported using the partial eta squared (η_p^2) as an effect size, with $\eta_p^2 \geq 0.01$ representing a small effect, $\eta_p^2 \geq 0.06$ a medium effect, and $\eta_p^2 \geq 0.14$ a large effect (Fritz et al., 2012). Subsequent to the ANOVA, post-hoc Bonferroni comparisons assessed the inter-group differences (PG vs TG; PG vs CG; and TG vs CG) for climbing ability, anxiety, self-confidence and IA from pre- to post-intervention. Post-hoc pairwise *t*-test comparisons were used to explore the source of differences in the pre-post scores between groups for each significant ANOVA. Cohen's *d* was used to indicate effect size (ES) (Cohen, 1992). ES was calculated as the mean pre-post difference divided by the pooled standard deviation of the change scores. The threshold for ES was considered as follows:

small ($d \leq 0.20$), moderate ($0.20 < d \leq 0.50$), large ($0.50 < d \leq 0.80$), and very large $d > 0.80$).

All tests were conducted as two-side, with a *p*-value of less than 0.05 considered statistically significant. Statistical analyses were performed using STATA version 16.0 (Stata Corp, College Station, TX, USA).

Results

On-sight climbing ability ranged from uncompleted lead climbing (ranging from zero) to a level of 7a. All participants practiced outdoor climbing between 1 and 2 days per week. The psychological training intervention lasted between 65 and 193 days, with the number of sessions ranged from four to five. This variation in the number of sessions was due to differences in the causes and triggers of fear, personality characteristics, and psychological abilities. The duration of the psychological training intervention was contingent on the availability of participants to climb every weekend.

Statistical power analysis revealed that the probability of detecting a medium effect size with one-way ANOVA in the study sample was 63.6%. A large effect size ($f \geq 0.49$) was required for the results to be statistically significant ($p < 0.05$). The calculated power to detect the hypothesised medium effect for the 3 (Group) x 2 (Time) ANOVA was 84.1%, with a sensitivity to detect a medium to large effect size ($f \geq 0.30$).

Descriptive characteristics, along with baseline scores for anxiety, self-confidence, and IA for the PG, TG, and CG, are shown in Table 3. Regarding the baseline one-way ANOVAs, the statistical power to detect a medium effect size ranged between 5.79% and 58.99%. This indicated potential underpowering for certain baseline measures, especially those with power below 50% (See Table 3). Despite this, variables such as Not-Distracting and Noticing exhibited a large effect size (η^2 of 0.19 and 0.16, respectively) and a power greater that 50%. Given their notable effect sizes and relative statistical power, these variables were included as covariates in the subsequent repeated-measure ANCOVAs to control for their potential impact on the intervention. Moreover, in response to the observed small and medium effect size for the pre-test score of Outdoor Climbing Days per Week ($\eta^2 = 0.13$), Years Climbing ($\eta^2 = 0.05$), Not-Worrying ($\eta^2 = 0.05$), Emotional Awareness ($\eta^2 = 0.08$), Self-Regulation ($\eta^2 = 0.11$), and Body Listening ($\eta^2 = 0.10$), these variables were also included as separate covariates in the repeated-measure ANOVA to further potential impact on the intervention.

After individually adjusting for several covariates, the analyses showed that none of the covariates had a significant effect on Climbing Ability (F values between 0.08 and 2.33, all *p* values < 0.05, η_p^2 between 0.01 and 0.22), Cognitive Anxiety (F values between 0.14 and 2.17, all *p* values < 0.05, η_p^2 between 0.02 and 0.21), and Self-Confidence (F values between 0.14 and 2.78; all *p* values < 0.05; η_p^2 between 0.02 and 0.25). For example, when adjusting for Outdoor Climbing Days per Week, the effect on Climbing Ability ($F = 0.17$, $p = 0.918$, $\eta_p^2 = 0.02$) and Cognitive Anxiety ($F = 0.14$, $p = 0.936$, $\eta_p^2 = 0.02$) remained non-significant. This pattern was consistent across all covariates, underlining the efficacy of the intervention independent of these factors for climbing level and anxiety. However, regarding Somatic Anxiety, only the Self-Regulation subscale was found to significantly influence the association ($F = 3.42$, $p = 0.03$, $\eta_p^2 = 0.29$). This was the only instance where a covariate had a notable impact, underscoring the importance of considering Self-Regulation in the context of somatic anxiety within the climbing community (Supplementary Table S1).

For the MAIA variables, adjustments were made only for Outdoor Climbing Days per Week and Years Climbing, since the other covariates (Not-Worrying, Emotional Awareness, Self-Regulation, and Body Listening) were subscales of the MAIA, and exhibited high correlations among themselves, indicating collinearity issues (as evidenced by the correlation data shown in Supplementary Table S2). Significant interactions were observed for the Emotional Awareness subscale when adjusting for Outdoor Climbing Days per Week ($F = 3.33$, $p = 0.036$, $\eta_p^2 = 0.29$). A similar trend was observed for the Body Listening subscale, with significant interactions found for Years Climbing ($F = 7.34$, $p = 0.001$, $\eta_p^2 = 0.47$).

Table 3. Descriptive characteristics and baseline scores for anxiety and interoceptive awareness questionnaires shown as mean (standard deviation).

	All ($n = 31$)	Control Group ($n = 10$)	Training Group ($n = 10$)	Psychological Group ($n = 11$)	ANOVA F (2,28)	*p*	η^2	Power (%)
Age	33.23 (6.84)	33.19 (8.05)	34.03 (6.04)	32.55 (6.93)	0.12	0.891	0.01	6.60
Years Climbing	5.55 (4.21)	4.30 (2.41)	5.70 (5.91)	6.55 (3.72)	0.74	0.486	0.05	16.29
Outdoor Climbing Days per Week	1.55 (0.51)	1.43 (0.48)	1.6 (0.52)	1.73 (0.47)	2.09	0.143	0.13	39.22
Intervention Duration (Days)	119.11 (24.26)	117.17 (4.94)	116.13 (3.80)	123.58 (41.18)	0.28	0.757	0.02	9.00
Climbing Ability[a]	11.26 (4.45)	11.7 (1.77)	12.00 (2.00)	10.18 (7.14)	0.49	0.616	0.03	12.38
Anxiety measures								
Cognitive anxiety	13.80 (3.29)	13.2 (3.1)	14.1 (4.3)	14.1 (2.6)	0.24	0.790	0.02	8.57
Somatic Anxiety	15.12 (3.34)	14.5 (3.5)	15.8 (2.7)	15.1 (3.9)	0.36	0.699	0.03	10.24
Self-confidence	9.74 (2.2)	10.0 (2.4)	9.20 (1.8)	10.0 (2.4)	0.45	0.643	0.03	11.56
Interoceptive Awareness measures								
Noticing	3.11 (0.9)	3.42 (0.5)	3.32 (0.8)	2.64 (1.1)	2.74	0.082	0.16	49.70
Not-Distracting	2.67 (0.61)	2.30 (0.6)	2.73 (0.5)	2.94 (0.6)	3.39	0.048	0.19	58.99
Not-Worrying	2.14 (0.81)	2.00 (0.7)	2.40 (0.6)	2.03 (1.1)	0.74	0.485	0.05	16.31
Attention Regulation	2.64 (0.73)	2.86 (0.7)	2.53 (0.6)	2.54 (0.9)	0.62	0.543	0.04	12.59
Emotional Awareness	4.12 (0.81)	4.22 (0.8)	4.34 (0.6)	3.82 (1.0)	1.22	0.311	0.08	24.36
Self-Regulation	2.68 (0.76)	2.92 (0.7)	2.8 (0.8)	2.36 (0.8)	1.65	0.210	0.11	31.82
Body Listening	2.69 (1.06)	3.00 (0.8)	2.87 (0.7)	2.24 (1.4)	1.61	0.218	0.10	31.08
Trusting	3.10 (1.12)	3.13 (0.6)	3.17 (0.8)	3.00 (1.7)	0.06	0.940	0.004	5.79

[a]On-sight climbing ability provided according to International Rock Climbing Research Association (IRCRA) scale.
η^2: Effect size-partial eta squared for baseline comparisons: $\eta^2 \geq 0.01$ small effect size; $\eta^2 \geq 0.06$ medium effect size; $\eta^2 \geq 0.14$ large effect size.

The non-adjusted models repeated-measures ANOVA, as shown in Table 4, revealed a significant Time x Group interaction for Climbing Ability ($F(2,28) = 14.23$, $p < 0.001$, $\eta_p^2 = 0.50$), Cognitive Anxiety ($F(2,28) = 8.63$, $p = 0.001$, $\eta_p^2 = 0.38$), Somatic Anxiety ($F(2,28) = 9.98$, $p = 0.005$, $\eta_p^2 = 0.29$), and Self-Confident ($F(2,28) = 26.87$, $p < 0.001$, $\eta_p^2 = 0.66$). Further examination of post-hoc Bonferroni-corrected comparisons indicated that the main effect of the study group on the change in scores from pre-to-post intervention was found between PG vs CG in Climbing Ability ($p < 0.01$), Cognitive ($p < 0.001$), and Somatic Anxiety ($p < 0.01$), and Self-Confidence ($p < 0.001$). In contrast, when comparing PG vs TG, a significant effect on the change in scores from pre-to-post intervention was found in Climbing Ability ($p < 0.05$), Somatic Anxiety ($p < 0.001$), and Self-Confidence ($p < 0.001$).

Repeated measures ANOVA showed a significant Time x Group interaction for several IA subscales derived by the MAIA questionnaire, such as the Noticing ($F(2, 28) = 3.78$, $p = 0.035$, $\eta_p^2 = 0.21$); Self-Regulation ($F(2, 28) = 8.43$, $p = 0.001$, $\eta_p^2 = 0.37$), Body Listening ($F(2, 28) = 16.99$, $p < 0.001$, $\eta_p^2 = 0.55$) and Trusting scores ($F(2, 28) = 6.93$, $p < 0.003$, $\eta_p^2 = 0.33$) (see Table 4). A non-significant interaction was found for Not-Worrying, Not-Distracting, Emotional Awareness, and Attention Regulation subscales (F between 1.22 and 3.18; all p values > 0.05). Post-hoc Bonferroni analyses revealed significant differences for change scores from pre to post comparison between PG vs CG in Self-Regulation ($p < 0.001$), Body Listening ($p < 0.001$) and Trusting ($p < 0.01$). When comparing PG and TG, significant differences were found in change scores from pre-to-post for Body Listening ($p < 0.001$) and Trusting ($p < 0.05$).

Post-hoc t-tests showed a significant improvement in climbing ability in PG with a mean difference (95% confidence interval) of 5.54 (95% CI [2.10, 8.99]; ES = 1.37) and of 0.80 (95% CI [0.14, 1.46]; ES = 0,57) in TG. Moreover, post-hoc tests for the CSAI-2 R questionnaire showed that cognitive anxiety scores also improved in both PG (−5.18; 95% CI [−7.30, −3.06]; ES = −1.85) and TG (−2.80; 95% CI [−4.84, −0.75]; ES = −1.05), while somatic anxiety scores was only improved for PG (−5.72; 95% CI [−8.09, −3.36]; ES = −1.68). Self-confidence also improved in both PG (5.00; 95% CI [3.80, 6.20]; ES = 2.86) and TG (0.90; 95% CI [−0.19; 1.99] (1.52); ES = 0.46 for TG). Finally, all evaluated CSAI-2 R parameters remained unchanged for CG ($p > 0.05$) (see Table 4 and Figure 2).

Post-hoc t-tests for the MAIA questionnaire revealed changes at the PG for Noticing (0.95; 95% CI [0.16, 1.74]; ES = 0.99); Attention Regulation (0.86; 95% CI [0.36, 1.35]; ES = 0.99), Self-Regulation (1.29; 95% CI [0.66, 1.93]; ES = 1.79), Body Listening (1.67; 95% CI [0.97; 2.36]; ES = 1.84) and, Trusting (1.42; 95% CI [0.46; 2.38]; ES = 1.40). TG showed changes in the MAIA subscales of Attention Regulation (0.34; 95% CI [−0.04; 0.72]; ES = 0.28) and Self-Regulation (0.50; 95% CI [−0.11; 1.11]; ES = 0.45). Moreover, all IA parameters measured by the MAIA questionnaire remained unchanged for the CG ($p > 0.05$), except for the Not-Distracting subscale, which showed a significant change ($p = 0.026$) (see Table 4).

Discussion

The effect of a psychological training intervention based on emotional regulation on anxiety and climbing performance was investigated in women climbers with fear of falling. Results supported our initial hypothesis in that a psychological training intervention appears to reduce anxiety levels and improve climbing ability, self-confidence and IA in women climbers with fear of falling.

Previous literature has described anxiety-induced impairments in climbing efficiency, including longer contact times with climbing holds (Draper et al., 2008; Pijpers et al., 2005), more frequent exploratory movements or longer climbing time (Nieuwenhuys et al., 2008), the use of more holds to progress climbing (Green & Helton, 2011; Green et al., 2014; Pijpers et al., 2006) and shorter climbing distances (Green et al., 2014). Accordingly, Giles et al. (2014) hypothesised that climbing performance might be improved through a reduction in anxiety and an increasing in self-confidence. Therefore, our results support this hypothesis, demonstrating that a proper balance

Table 4. Mean (SD) of self-reported climbing ability, CSAI-2 R and MAIA questionnaires for pre-post-test in all groups.

	Control Group ($n = 10$)		Training Group ($n = 10$)		Psychological Group ($n = 11$)		Interaction (Time x Group)			Effect Size[a]		
	Pre	Post	Pre	Post	Pre	Post	$F_{(2,28)}$	p	η_p^2	PG vs CG	PG vs TG	TG vs CG
Climbing Ability	11.7 (1.8)	10.8 (4.2)	12.0 (2.0)	12.8 (2.2)*	10.2 (7.1)	15.7 (3.5)**	14.23	<0.001	0.50	+++	+++	++
Anxiety measures												
Cognitive Anxiety	13.2 (3.1)	13.0 (3.2)	14.1 (4.3)	11.3 (3.6)**	14.1 (2.6)	8.9 (2.4)***	8.63	0.001	0.38	+++	++	+++
Somatic Anxiety	14.5 (3.5)	14.2 (4.2)	15.8 (2.7)	15.8 (4.1)	15.1 (3.9)	9.4 (1.7)***	9.98	0.005	0.29	+++	+++	-
Self-Confidence	10.0 (2.4)	10.2 (2.2)	9.2 (1.8)	10.1 (2.5)*	10.0 (2.4)	15.0 (2.1)***	26.87	<0.001	0.66	+++	+++	+
Interoceptive Awareness measures												
Noticing	3.4 (0.5)	3.4 (0.5)	3.32 (0.8)	3.47 (0.6)*	2.6 (1.1)	3.6 (0.8) *	3.78	0.035	0.21	+++	+++	+
Not-Distracting	2.3 (0.6)	2.7 (0.4) *	2.73 (0.5)	2.5 (0.8)	2.9 (0.6)	3.1 (0.5)	1.64	0.213	0.10	+	+	++
Not-Worrying	2.0 (0.7)	1.8 (0.9)	2.4 (0.6)	2.57 (0.8)	2.0 (1.1)	2.6 (0.9)	1.26	0.300	0.08	++	+	+
Attention Regulation	2.9 (0.7)	2.0 (0.5)	2.53 (0.5)	2.87 (0.5) *	2.5 (0.9)	3.4 (0.7)**	3.18	0.057	0.18	+++	+++	+
Emotional Awareness	4.2 (0.8)	4.3 (0.5)	4.34 (0.6)	4.42 (0.8)	3.8 (1.0)	4.4 (0.4)	1.22	0.312	0.08	+++	+	-
Self-Regulation	2.9 (0.7)	2.7 (0.7)	2.80 (0.8)	3.30 (0.9) *	2.4 (0.8)	3.7 (0.7)***	8.43	0.001	0.37	+++	+++	+
Body Listening	3.0 (0.8)	2.9 (6.7)	2.9 (0.7)	2.63 (0.6)	2.2 (1.4)	3.9 (0.9)***	16.99	<0.001	0.55	+++	+++	-
Trusting	3.1 (0.6)	2.9 (1.0)	3.2 (0.8)	3.3 (0.8)[c]	3.0 (1.7)	4.4 (0.7)**	6.93	0.003	0.33	+++	+++	+

* Significantly different from pre-and post-test: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

[a]Effects size (Cohen´s d) for pre-post pairwise t-test comparisons: - small effect ($d \leq 0.20$); + moderate effect ($d > 0.20$); ++ large effect ($d > 0.50$); +++ very large effect ($d > 0.80$).

[b]Effect Size (Cohen´s d) for Climbing Ability, CSAI-2 R and MAIA Scores in PG and TG Relative to CG after Intervention.

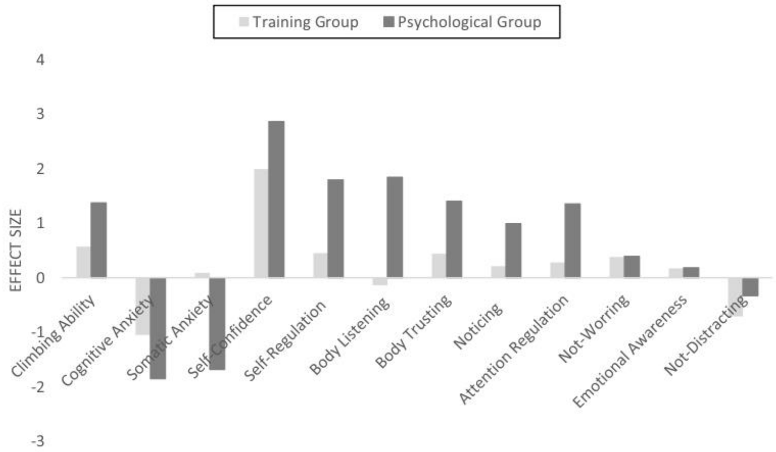

Figure 2. Effect size (Cohen´s *d*) for Climbing Ability, CSAI-2 R and MAIA scores in PG and TG relative to CG after intervention.

between anxiety and self-confidence may have a positive effect on climbing efficiency and consequently, climbing ability. Similarly, our findings are in accordance with Brown and Fletcher (2016) who reported in a systematic review that psychological training interventions seem to have a positive effect on sports performance. Nevertheless, it is important to address the self-reported measure of climbing ability employed in our study, which has demonstrated validity across various contexts (Draper et al., 2011; Fryer et al., 2017). However, we must acknowledge the potential for inherent bias in self-reported improvements following an intervention. Unlike prior studies, our investigation evaluated self-reported improvements after an intervention. Given the absence of an independent rating, such as assessment by an observing trainer, there is a possibility that participants´ perceptions of improvement could be influenced by their involvement in the psychological training intervention. Therefore, any self-reported improvements in climbing ability should be considered with cautious interpretation.

Regarding to IA, the Attention Regulation, Self-Regulation, Noticing, Body Listening and Trusting subscales of the MAIA showed significant changes after the psychological training intervention, accounting for five out of eight IA subscales. This finding align with a growing body of literature that highlight the role of awareness and interoceptive self-regulation of bodily sensations in facilitating emotional regulation (Critchley & Garfinkel, 2017b; Füstös et al., 2013). The observed improvement in IA following the psychological training intervention may partly indicate a enhance in participants´ anxiety coping skills associated with fear of falling. Moreover, the effectiveness of psychological training as a treatment to reduce anxiety was consistent with studies that have implemented intervention programmes targeting the dysregulation of core emotions, such as fear (Sakiris & Berle, 2019).

For the second purpose of this study, our hypothesis, as shown in Figure 3, was that there would be a stronger effect of psychological training than physical training in climbing ability, anxiety, self-confidence and the eight subscales of IA after comparing the groups. Our results showed that PG participants experienced an average increase of 54.5% in on-sight climbing ability, in contrast to a 6.8% increase in the TG. Conversely, the GC group experienced a 6% decrease in on-sight climbing ability. These results may reflect the impact that a psychological training intervention has on climbing performance, compared to the absence of specific treatment in climbers with fear of falling. Furthermore, cognitive anxiety and self-confidence were improved by both, the PG and TG. However, the decrease in anxiety was greater for the PG and this group also reduced somatic anxiety compared to TG. In contrast, no changes were observed in any of the variables for the CG. The increase in climbing ability in the TG could be due to physical training. Moreover, the decrease of cognitive anxiety observed in the TG could be explained by the fact that specific sport domain abilities training (finger strength, balance, technique, etc.), decreased hazard perception or risk of falling (Jakus & Shaw, 1996; Philippe et al., 2019). It is already well known that fear of falling is related to strength (Yardimci et al., 2021) and balance (Binda et al., 2003); and feeling strong and balanced is like feeling safe (emotional well-being) (Bernstein & Mcnally, 2018). Some authors even have suggested that paradoxically, fear of falling by itself is considered a risk factor for falls (Friedman et al., 2002; Lavedán et al., 2018). Thus, the better pre-post results in climbing ability for the PG vs TG may be explained by the greater decrease in both cognitive and somatic anxiety and increase in self-confidence for the PG compared to the other groups.

Regarding the comparison of IA between groups, the changes observed in the TG related to IA were consistent with previous findings that suggest regular exercise practice has a positive influence on emotional regulation, particularly in attentional and emotion control (Giles et al., 2017). The differences in the attention regulation subscale of MAIA in the PG and TG, along with the improvement in climbing ability, align with the previous scientific literature on climbing. For example, Garrido-Palomino et al. (2020)

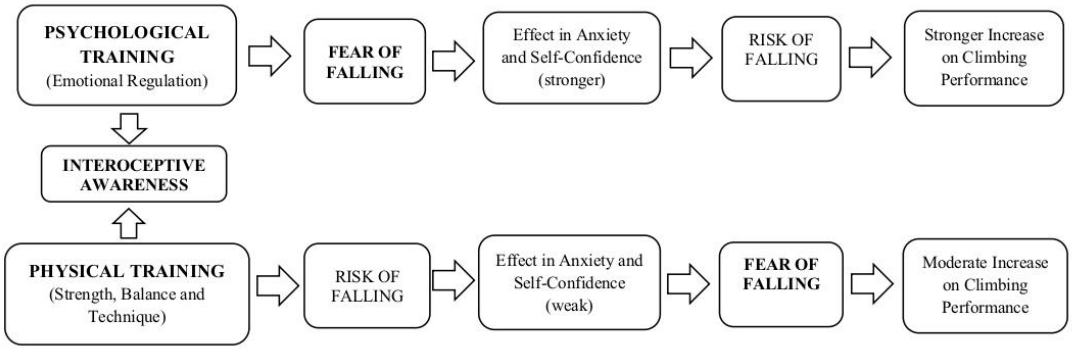

Figure 3. Hypothesized effects of psychological and physical training on fear of falling in women climber.

demonstrated that elite climbers exhibited greater attentional control compared to expert climbers, suggesting that attentional control could be a determinant of climbing performance. Overall, it seems that both psychological and physical training could improve, directly or indirectly, attentional control as part of emotional regulation in climbers affected by anxiety, thereby enhancing climbing ability (see Figure 3). However, it is crucial to note, as indicated by the results, that the ability of Self-Regulation appears to have a significant impact on Somatic Anxiety. These findings underscore the importance of developing effective self-regulation strategies to coping with somatic anxiety in climbing. Moreover, it is important to highlight, that the Years of Climbing and the Outdoor Climbing Days per Week seem to have a substantial effect on the Emotional Awareness and Body Listening, influencing the development of interoceptive awareness among climbers.

The C-HIPPER study provides novel insight into the effects of an emotional regulation-based psychological training intervention on anxiety and climbing performance in women climbers with fear of falling. However, there are several potential limitations that need to be considered when interpreting results. First, participants were not randomly assigned to the groups. The allocation methods were based on whether participants were undergoing climbing training with a sports specialist and their preference for starting psychological training. This led to the assignment of some individuals to the PG, others to the TG, and still others to the CG. It is important to note that within the PG and CG, participants continued their regular climbing activity training without a sports specialist, unlike the TG. While this allocation method aimed to reflect real-world scenarios, it could potentially limit the generalisability of the results. Furthermore, the intervention was concluded when each participant in the PG expressed no longer feeling fear of falling. Neither the TG nor the CG were asked the same question about fear of falling as the PG at four months, which does not allow us to affirm that the fear of falling remained in these groups. This assignment of intervention conclusion could have led to a predisposition towards improvements in CSAI scores. This likely introduced bias and might have inflated the observed effects of the intervention, which should be considered when interpreting the results.

Second, all participants met the inclusion and exclusion criteria, and no significant differences were observed between groups on the main parameters at baseline. Despite this, the low statistical power, and the presence of medium to large effect sizes for several baseline scores indicate that it is difficult to definitively assert the groups initial homogeneity. The sample size of 31 participants limited the power to detect subtle between-group differences in the pre-test comparisons, potentially contributing to Type II error. Although certain differences were accounted for in subsequent ANCOVA analyses, the possibility of overlooking smaller effect sizes and nuanced differences cannot be discounted. This limitation is crucial when interpreting the results and considering their generalisation to a broader population of women climbers with fear of falling.

Third, certain subscales of the MAIA questionnaire used in this study, such as Non-Distracting and Not-Worrying, exhibited very low internal consistency values (ranging from 0.40 to 0.48). While the overall internal consistency was good (Cronbach's α of 0.90 for the total scale), these subscales raise concerns about their reliability. Although a revised version of the MAIA questionnaire has been suggested for better psychometric properties (Mehling et al., 2018), we used the validated version (Valenzuela-Moguillansky & Reyes-Reyes, 2015) due to linguistic limitation. Future research could explore the application of the revised MAIA questionnaire to enhance IA assessment in diverse linguistic contexts.

Fourth, despite the improvement in climbing performance in the PG, the experimental design of our study did not provide a quantified measure of fear of falling. Furthermore, although the use of the MAIA questionnaire allowed us to evaluate the impact of the intervention on one of the components of emotional regulation, a dimension not previously explored in climbing research, we need to be cautious. The lack of a follow-up period does not allow us to ensure the long-term control of the fear of falling or the maintenance of the observed changes in anxiety, climbing ability, and IA after the psychological training intervention. Additionally, it is important to note that the intervention was individualised and comprised multiple components. As a result, it should be acknowledged that the observed improvements cannot be solely attributed to any specific component(s) of the intervention. Furthermore, when considering the improvements in climbing ability, it is noteworthy that within the PG, there was a considerable variability in the extend of improvements, as indicated by the larger SD (Table 2). This variability underscores the diverse response to the psychological training intervention and suggests that other factors beyond the intervention may have influenced individual climbing performance outcomes. Finally, the specifics of individual physical training, such as hour per session or climbing exercises performed in daily life, were not recorded in any group (PG, TG or CG). This oversight could influence the observed effects of the intervention and should be considered in future studies.

Despite acknowledging these limitations, it is important to highlight the strengths of our study. First, our research provides novel insights into the effects of an emotional-based psychological training intervention on anxiety and climbing performance in women climbers with fear of falling, contributing a unique perspective to the literature. Second, the detail description of our psychology intervention methodology promotes transparency and facilitates replication efforts. Third, the use of the MAIA questionnaire provides a quantified measure of IA as part of emotional regulation, contributing to the robustness of our findings. Lastly, our focus on women climbers, an underrepresented group within the climbing community, adds value to our research and could be of interest to both researchers and practitioners in the field.

Based on our results and considering that falling is part of sport climbing, our findings may have important practical implications. We argue that psychological training may directly modulate fear of falling according to the physical and psychological characteristics of the athletes and their context. It is also likely that physical training influences the risk of falls by enhancing strength, technique and balance, indirectly modulating fear of falling. Consequently, fear of falling and falling anxiety should be addressed by a specialised psychologist. Sports psychologists should address fear of falling in climbing by acting on interoceptive processing as a key of emotional regulation.

In conclusion, our results suggest that a psychological training intervention focused on emotion regulation may lead to significant improvements in interoceptive awareness, reduced anxiety levels, and increases in climbing ability, and self-confidence in women climbers with fear of falling. These findings highlight the importance of considering psychological training as a valuable tool for climbers and their coaches to address anxiety and enhance climbing performance, acknowledging the inherent risks associated with falling in the sport. While our findings are encouraging, we acknowledge the small sample size of the study as a limitation, underscoring the importance of replicating the study with a more extensive participant pool to solidify these preliminary insights. Despite this limitation, the consistent positive outcomes observed across various metrics in our study offer a compelling foundation for the continued exploration and integration of psychological training in enhancing the climbing experience for women facing the challenge of fear of falling in the sport.

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Supplementary tables

Supplementary Table 1

Results of Repeated Measures ANCOVAs for Climbing Ability, Cognitive Anxiety, and Self-Confidence.

	Interaction (Time x Group x Covariate)																	
	Outdoor Climbing Days per Week			Years Climbing			Emotional Awareness			Not-Worrying			Self-Regulation			Body Listening		
	F	*p*	η^2	F	*p*	η^2	F	*p*	η^2	F	*p*	η^2	F	*p*	η^2	F	*p*	η^2
Climbing Ability	0.17	0.918	0.02	0.97	0.423	0.10	0.33	0.802	0.04	0.72	0.550	0.08	0.08	0.968	0.01	2.33	0.099	0.22
Cognitive Anxiety	0.14	0.936	0.02	1.62	0.211	0.16	0.55	0.655	0.06	0.91	0.449	0.09	0.35	0.791	0.04	2.17	0.117	0.21
Somatic Anxiety	1.17	0.339	0.12	0.64	0.594	0.07	0.18	0.906	0.02	0.83	0.492	0.09	3.42	0.033	0.29	2.57	0.076	0.24
Self-Confidence	0.24	0.870	0.03	2.14	0.120	0.20	0.14	0.937	0.02	1.36	0.278	0.14	2.78	0.062	0.25	1.62	0.211	0.16

Supplementary Table 2

Pearson Correlation of Mean Differences in Pre- and Post- MAIA Subscale Scores

	Noticing	Not-Distracting	Not-Worrying	Attention Regulation	Emotional Awareness	Self-Regulation	Body Listening	Trusting
Noticing	1							
Not-Distracting	0.200	1						
Not-Worrying	0.014	-0.067	1					
Attention Regulation	0.300	-0.005	0.467	1				
Emotional Awareness	0.692**	0.182	-0.243	0.578**	1			
Self-Regulation	0.402	0.037	-0.019	0.310	0.320	1		
Body Listening	0.452*	0.191	0.025	0.665**	0.535**	0.514**	1	
Trusting	0.479*	-0.090	0.035	0.693**	0.588**	0.529**	0.657**	1
Mean	0.39	0.05	0.21	0.47	0.25	0.55	0.47	0.47
SD	0.72	0.65	1.13	0.70	0.93	1.03	1.22	1.27

*Statistical significance: *$p < 0.05$; ** $p < 0.01$

ANNEX VI. SOLICITUD DE AUTORIZACIÓN PARA EL DEPÓSITO DE LA TESIS DOCTORAL (REAL DECRETO 99/2011, DE 28 DE ENERO)

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ANEXO I
SOLICITUD DE AUTORIZACIÓN PARA EL DEPÓSITO DE LA TESIS DOCTORAL (REAL DECRETO 99/2011, DE 28 DE ENERO)

D./Dª. **Inmaculada Garrido Palomino**, investigador en formación del programa de doctorado **8203 Ciencias de la Salud**, regulado por el Real Decreto 99/2011, de 28 de enero, *por el que se regulan las enseñanzas oficiales de doctorado*, una vez completada su formación doctoral y habiendo superado la evaluación definitiva de su plan de investigación, solicita a la Comisión Académica del programa de doctorado arriba citado autorización para proceder al depósito, en la Secretaría General de esta Universidad, de la tesis doctoral titulada "**Funcionamiento cognitivo y emocional relacionado con el rendimiento en escalada**", dirigida por el/los Drs. D./Dª. **Vanesa España Romero.**

En Cádiz, a 10 de Abril de 2024

Firmado por
GARRIDO
PALOMINO

Fdo.: Inmaculada Garrido Palomino

IMPORTANTE
La presente solicitud deberá acompañarse del Informe favorable del director (es) de la tesis, así como de un ejemplar de la tesis doctoral y de una copia del Documento de Actividades del doctorando.

Informe administrativo de la Oficina de Posgrado

Revisado el expediente de doctorado de D./Dª.___________ _____ ______________, la Oficina de Posgrado, considerando el cumplimiento necesario de los requisitos administrativos establecidos, informa que el interesado se encuentra en disposición de hacer el depósito de su tesis doctoral en la Secretaría General de la Universidad.

(Sello de la Oficina)

En Cádiz, a de de 20

Fdo.:_________________________

Sr. Presidente de la Comisión Académica del Programa de Doctorado___________

ANNEX VII. MODELO DE INFORME FAVORABLE DE LA DIRECTORA DE LA TESIS PARA EL DEPÓSITO DE TESIS DOCTORALES DESARROLLADAS DE ACUERDO CON EL REAL DECRETO 99/2011, DE 28 DE ENERO.

UCA Universidad de Cádiz

Escuela de Doctorado de la Universidad de Cádiz
(EDUCA)

Hospital Real
Oficina de Posgrado
Universidad de Cádiz
Plaza Falla, 8
11002 Cádiz

ANEXO II
MODELO DE INFORME FAVORABLE DEL DIRECTOR(ES) DE LA TESIS PARA EL DEPÓSITO DE TESIS DOCTORALES DESARROLLADAS DE ACUERDO CON EL REAL DECRETO 99/2011, DE 28 DE ENERO

D./Dª. **Vanesa España Romero**, directora de la tesis doctoral de D./Dª. **Inmaculada Garrido Palomino**, alumna del programa de doctorado **8203 Ciencias de la Salud,** regulado por el Real Decreto 99/2011, de 28 de enero, por el que se regulan las enseñanzas oficiales de doctorado, informa favorablemente la solicitud de autorización para el depósito de la tesis doctoral de D./Dª. **Inmaculada Garrido Palomino,** titulada "**Funcionamiento cognitivo y emocional relacionado con el rendimiento en escalada**", y desarrollada de acuerdo con los requisitos de control de calidad para las tesis doctorales recogidos en la memoria del programa de doctorado de referencia.

En Cádiz, a 13 de Abril de 2024

Fdo.: Firmado por ESPAÑA ROMERO VANESA - __________ Fdo.: ____________________

NOTA
El Informe deberá venir acompañado de un pronunciamiento expreso del director (o directores) de la investigación acerca de la adecuación del resultado de la investigación (la tesis) al proyecto presentado en su momento, el correcto desarrollo del proceso de formación doctoral del doctorando y la validez y la oportunidad de los resultados de la investigación plasmados en la tesis.

Sr. Presidente de la Comisión Académica del Programa de Doctorado ____________

ANNEX VIII. INFORME DE LA DOCTORANDA PARA LA INCLUSIÓN DE TRABAJOS EN LA MODALIDAD DE TESIS POR COMPENDIO DE PUBLICACIONES.

UCA Universidad de Cádiz

educa Escuela de Doctorado de la Universidad de Cádiz

Informe de la doctoranda para la inclusión de trabajos en la modalidad de tesis por compendio de publicaciones

La investigadora **Inmaculada Garrido Palomino** con DNI **26039180Y**, como autora principal de las tres publicaciones que componen la tesis doctoral titulada: **FUNCIONAMIENTO COGNITIVO Y EMOCIONAL RELACIONADO CON EL RENDIMIENTO EN ESCALADA**, expresa su mayor contribución al trabajo realizado, con gran relevancia en sus aportaciones frente al resto de los firmantes.

En Cádiz a 9 de abril de 2024

Firmado por GARRIDO PALOMINO INMACULADA - ***3918** el día 09/04/2024 con un certificado emitido

Fdo. Inmaculada Garrido Palomino

ANNEX IX. DOCUMENTOS DE CONFORMIDAD Y RENUNCIA DE COAUTORES

UCA Universidad de Cádiz

Thesis by compendium of publications.
Document of agreement and resignation of co-authors.

D. /Dª.: _**Simon Fryer** (553207848), **Dave Giles** (145017276), **Javier J. Gonzalez-Rosa** (31692232A) y **Vanesa España Romero** (48913438M) co-author of the following publication: "Attentional differences as a function of rock climbing performance".

In accordance with the **Article 23.4** of the **Regulation UCA CG06-2012, June 27, 2012, which regulates the ordinance of doctoral studies at the University of Cádiz (BOUCA No. 208).**

States his/her approval to the presentation of this publication as a part of the doctoral thesis written by D. /Dª. _**Inmaculada Garrido Palomino** (26039180Y), entitled "Cognitive and emotional functioning related to climbing performance ".

And expresses his/her resignation to present said publication as a part of another doctoral thesis at any other University.

In Cádiz, 9 of April, 2024

Firmado por ESPAÑA ROMERO VANESA - 48913438M el día 10/04/2024 con un certificado emitido por

Dave Giles | Simon Fryer | Javier J. González-Rosa

Signed: ______________________________

Universidad de Cádiz

Thesis by compendium of publications.
Document of agreement and resignation of co-authors.

D. /Dª.: **Dave Giles** (145017276), **Simon Fryer** (553207848), **Jose Luis González Montesinos** (31252266G), Vanesa España Romero (48913438M) co-author of the following publication: **"Cognitive function of climbers: An exploratory study of working memory and climbing performance"**.

In accordance with the **Article 23.4** of the **Regulation UCA CG06-2012, June 27, 2012, which regulates the ordinance of doctoral studies at the University of Cádiz (BOUCA No. 208).**

States his/her approval to the presentation of this publication as a part of the doctoral thesis written by D. /Dª. _**Inmaculada Garrido Palomino** (26039180Y), entitled "Cognitive and emotional functioning related to climbing performance ".

And expresses his/her resignation to present said publication as a part of another doctoral thesis at any other University.

In Cádiz, 9 of April 2024

Simon Fryer

Dave Giles

GONZALEZ MONTESINOS JOSE LUIS - 31252266G

Signed: ______________________________

Firmado por ESPAÑA ROMERO VANESA - 48913438M el día 10/04/2024 con un certificado emitido por AC FNMT Usuarios

Universidad de Cádiz

Tesis por compendio de publicaciones
Documento de conformidad y renuncia de coautores

D./Dª.: **Vanesa España Romero** con DNI **48913438M** coautor de la publicación que se identifica a continuación: **"Role of emotional intelligence on rock climbing performance".**

de acuerdo con lo establecido en el **Artículo 23.4** del **Reglamento UCA/CG06/2012, de 27 de junio de 2012, por el que se regula la ordenación de los estudios de doctorado en la Universidad de Cádiz (BUOCA nº 208).**

Manifiesta su conformidad para la presentación de la citada publicación como parte de la tesis doctoral de D./Dª. **Inmaculada Garrido Palomino** con DNI **26039180Y**, titulada **"Funcionamiento cognitivo y emocional relacionado con el rendimiento en escalada"**.

Y expresa su renuncia a presentar la citada publicación como parte de otra tesis doctoral en cualquier otra universidad.

En Cádiz, a 13 de Abril de 2024

Firmado por ESPAÑA ROMERO VANESA - 48913438M el día 08/04/2024 con un certificado emitido por AC FNMT Usuarios

Fdo.: ______________________

Universidad de Cádiz

Tesis por compendio de publicaciones
Documento de conformidad y renuncia de coautores

D./Dª.: **Vanesa España Romero** con DNI **48913438M** coautor de la publicación que se identifica a continuación: **"Fear of falling in women: A psychological training intervention improves climbing performance".**

de acuerdo con lo establecido en el **Artículo 23.4** del **Reglamento UCA/CG06/2012, de 27 de junio de 2012, por el que se regula la ordenación de los estudios de doctorado en la Universidad de Cádiz (BUOCA nº 208).**

Manifiesta su conformidad para la presentación de la citada publicación como parte de la tesis doctoral de D./Dª. **Inmaculada Garrido Palomino** con DNI **26039180Y**, titulada **"Funcionamiento cognitivo y emocional relacionado con el rendimiento en escalada"**.

Y expresa su renuncia a presentar la citada publicación como parte de otra tesis doctoral en cualquier otra universidad.

En Cádiz, a de Abril de 2024

Firmado por ESPAÑA ROMERO VANESA - 48913438M el día 08/04/2024 con un certificado emitido por AC
Fdo.: FNMT Usuarios

SHORT CURRICULUM VITAE

Personal information

Inmaculada Garrido Palomino

(signature on articles: Inmaculada Garrido-Palomino, Inma Garrido, Inmaculada Garrido)

Born: April the 19th of 1976. Jaén. Spain

Contact: inmaculada.garrido@uca.es +34 606168081

Education

1996-2001	Bachelor's degree in Psychology. University of Jaén. Spain
2011-2012	Master's in Psychology of Physical Activity and Sports. National Open University (UNED). Spain
2016-2017	Master's in Cognitive and Behavioral Neuroscience. University of Granada. Spain
2019-2024	PhD Student in Health Sport Sciences. University of Cádiz. Spain

Work Experience

2021-2022	Lecturer in the degree of Psychology, Social Psychology Department. University of Cadiz Duration: 1 month
2019-2020	Sports Psychologist - Research Project Pi0068-2018 Foundation for Biomedical Research Management Duration: 3 Months
2011-2018	Technical Employment Officer Andalusian Employment Service Duration: 84 Months
2004-2011	Project Officer Andalusian Foundation for Training and Employment Fund Duration: 96 Months

Research Experience

- Aspectos Fisiológicos y Psicológicos en Escalada: Proyecto C-HIPPER. Vanesa España Romero. Funded by the University of Cádiz. (PR2016-056). 2016-2017. 1,800 €.

- Actividades físicas en el medio natural en personas con depresión. Efectos sobre el bienestar psíquico y social. Estudio SONRÍE. Program for the financing of biomedical and health sciences i+D+I in health sciences in Andalusia. (PI0068 2018). 2019-2021. 60,174 €.

Publications

- **Inmaculada Garrido-Palomino**, Dave, Giles, Simon Fryer, José Luis González-Montesinos, Vanesa España-Romero **(In Press).** Cognitive function of climbers: an exploratory study of working memory and climbing performance**.** Spanish Journal of Psychology.
- **Inmaculada Garrido-Palomino** & Vanesa España-Romero (2023) Fear of falling in women: A psychological training intervention improves climbing performance, Journal of Sports Sciences, 41:16, 1518-1529, https://doi.org/10.1080/02640414.2023.2281157.
- **Garrido-Palomino, I**., Fryer, S., Giles, D., González-Rosa, J. J., & España-Romero, V. (2020). Attentional Differences as a Function of Rock Climbing Performance. Frontiers in Psychology, 11, 1550. https://doi.org/10.3389/fpsyg.2020.01550.
- **Garrido-Palomino, I.,** & España-Romero, V. Role of emotional intelligence on rock climbing performance (2019). RICYDE: Revista Internacional de Ciencias del Deporte, 15(57), 284–294. https://doi.org/10.5232/ ricyde2019.05706.
- Fryer, S. M., Giles, D., **Palomino, I. G.,** de la O Puerta, A., & España-Romero, V. (2018). Hemodynamic and Cardiorespiratory Predictors of Sport Rock Climbing Performance. Journal of Strength and Conditioning Research, 32(12), 3534–3541. https://doi.org/10.1519/JSC.0000000000001860
- Fryer, S., Stoner, L., Stone, K., Giles, D., Sveen, J., **Garrido, I.,** & España-Romero, V. (2016). Forearm muscle oxidative capacity index predicts sport rock-climbing performance. European Journal of Applied Physiology, 116(8), 1479–1484. https://doi.org/10.1007/s00421-016-3403-1.

- Giles, D., Romero, V. E., **Garrido, I.**, de la O Puerta, A., Stone, K., & Fryer, S. (2017). Differences in Oxygenation Kinetics Between the Dominant and Nondominant Flexor Digitorum Profundus in Rock Climbers. International Journal of Sports Physiology and Performance, 12(1), 137–139. https://doi.org/10.1123/ ijspp.2015-0651

- Nick Draper, David Giles, Volker Schöffl, Franz Konstantin Fuss, Phillip Watts, Peter Wolf, Jiří Baláš, Vanesa Espana-Romero, Gina Blunt Gonzalez, Simon Fryer, Maurizio Fanchini, Laurent Vigouroux, Ludovic Seifert, Lars Donath, Manuel Spoerri, Kelios Bonetti, Moreau, **Inmaculada Garrido**, Scott Drum, Stuart Beekmeyer, Jean Luc Ziltener, Nicola Taylor, Ina Beeretz, Franziska Mally, Arif Mithat Amca, Caroline Linhart & Edgardo Abreu (2015) Comparative grading scales, statistical analyses, climber descriptors and ability grouping: International Rock Climbing Research Association position statement, Sports Technology, 8:3-4, 88-94. https://doi.org/10.1080/19346182.2015.1107081

Conferences and Seminars

- Poster. "A Comparison of Emotional Intelligence in Elite and Expert rock climbers". Publication Details of the Proceedings: International symposium. Active brain for all: Exercise, cognition and mental health. Granada, Spain. 12th June, 2017. ISBN: 978-84-697- 3918-1

- Communication. "Is Vigilance related to Rock Climbing Performance?". Publication Details of the Proceedings: IV International Rock Climbing Research Congress. Chamonix, France. 9th-15th July, 2018.

- Poster. "Relationship between healthy outdoor physical activity and attencion". VI Symposium EXERNET. Research in Exercise, Health, and Well-being. "Exercise is Medicine". Pamplona, Spain. 19th-20th October, 2018.

- Communication. "Working Memory Functioning in Outdoor Climbers". 5th International Rock Climbing Research Congress. Tokyo, 11th-14th June, 2021.

- Communication. "A Case Study: Psychological Intervention Improves Climbing Performance". 5th International Rock Climbing Research Congress. Tokyo, 11th-14th June, 2021.

- Communication. "Impact of Emotions on Performance in Individual Sports" - I Virtual Congress of Sports Psychology. National Council of Sports Education. Mexico, 23rd November, 2021.

- Communication. "Psychological changes with the repeated practice of a specific route". 6th International Rock Climbing Research Congress. Bern, Switzerland. 7th –10th August, 2023.

Awards

2009	Andalusia Sports Awards: Award for the Best Andalusian Team. (Resolution of August 4, 2009, from the Dirección General de Planificación y Promoción del Deporte, announcing the Andalusia Sports Awards of 2008. BOJA No. 162, 20th August, 2009).
2010	Recognition by the jury at the XV Sports Gala of Jaén by the Association of Sports Journalists of Jaén.
2020	Award for the best oral communication. Manuel Ruiz-Muñoz, **Inmaculada Garrido-Palomino**, Juan Manuel Escudier-Vázquez, Sonia Ortega Gómez, Natalia Sánchez-Alarcón y Vanesa España-Romero. Efectividad de tratamiento de actividad física presencial y online en pacientes con depresión. Estudio SONRIE. II Congreso Internacional de Salud Mental FEAFES, Huelva, Spain.

Other merits

2010-2013	High Performance Athlete of Andalusia. Resolution of June 9, 2010, from the Secretaría General para el Deporte, regarding the Relación de Deporte de Rendimiento de Andalucía, corresponding to the first list of 2010. BOJA No. 124, 25th June, 2010.

2015-2017 High Performance Athlete of Andalusia. Resolution of June 3, 2015, from the Secretaría General para el Deporte, regarding the Relación de Deporte de Rendimiento de Andalucía, corresponding to the first list of 2015. BOJA No. 114, 15th June, 2015.

ACKNOWLEDGEMENTS [AGRADECIMIENTOS]

Empecé esta tesis como si fuera un juego, que es como a mí me gusta vivir la vida. Pero como en todos los juegos a los que nunca has jugado, hay que aprender a jugar de la mano de alguien que te contagie la pasión por aprender.

Estoy profundamente agradecida a mi directora de tesis y amiga, **Vanesa España Romero**, por haberme mostrado el mundo de la ciencia y haberse cruzado en mi camino, ya que ha supuesto un gran cambio para mi forma de pensar y mi enfoque como profesional. Gracias por haberme mostrado este proceso como un juego, haberme cogido de la mano y haberme enseñado tanto. Gracias por ser además amiga y haberme acompañado en escaladas imposibles y convertir esas fantasías en realidad. Y gracias por ayudarme a darle forma de investigación a mis curiosidades en escalada.

Me siento inmensamente agradecida a todas las escaladoras y escaladores que han participado en esta investigación, por su generosidad. Por cedernos su tiempo para que la ciencia en escalada avance y por ayudarnos a poner un granito de arena. Gracias por aportarnos tanto.

Al pequeño pero gran equipo del que me siento que formo parte, por estar y ser quienes sois. A **Manu** por su dulzura, su sensibilidad y su profesionalidad. A **Juanma** por su fortaleza y su entusiasmo contagioso. Y a **Sonia** por su buen hacer y su buena disposición. A **Simon** y **Dave** por la paciencia que han demostrado con mi inglés de Jaén.

A mi **abuelito** por haber llenado mi infancia de recuerdos maravillosos. Porque nunca me soltó la mano, y aunque ya no está, siempre me acompaña. Me emociona y me hace inmensamente feliz solo imaginar lo feliz que le hubiera hecho vivir y ver este momento.

A mi **madre**, por su resiliencia, por habernos enseñado a sonreír, a relativizar las dificultades y positivizar lo negativo. Porque desde bien pequeños nos ha animado a levantarnos después de caer, nos ha lavado las heridas y animado a seguir adelante. Por ser una luchadora y una valiente y haberme enseñado los valores como el respeto, la empatía, la responsabilidad, la voluntad, la honestidad, la compasión, el amor, el perdón y la gratitud, que forman mi forma de ser y trabajar.

A mi hermana **Mahme**, por haber estado y estar siempre a mi lado, saber entenderme o al menos respetarme y creer en mí. Porque en algunos momentos de mi vida ella ha sido la única y todo lo que he tenido. Porque siempre ha sabido estar ahí.

A mi familia **Palomino**, porque, aunque yo esté siempre lejos, siempre los siento cerca, por su sentido el humor y la alegría que desprenden.

A **Kate**, **Lorena**, **Alvarito**, **Nando**, **Patri**, **Alex**, **Dani "Puma"**, **Olatz**, **María**, **Boby y Sescun**, mi grupo de amigas y amigos sin monitor de Barbastro, que han sido mi familia durante los años que he vivido allí, han llenado mi vida de risas y alegría y se han interesado por lo que llamaban mi "cursito".

Me agradezco a mí misma el permitirme explorar un camino nuevo muy alejado de lo ya conocido, el autocuidado de no dejar nunca de dedicar tiempo al deporte, el actuar siempre con responsabilidad y coherencia ética y emocional, el ser trabajadora, constante, tenaz, entusiasta. Me doy gracias por no dejar de recordarme nunca a mí misma que estaba jugando y por tener fortaleza mental de aguantar un proceso que, a pesar de tomarlo como un juego, se hace largo.

Y especialmente, inmensamente agradecida a **Dani** quien más de cerca ha vivido este proceso, que me ha tratado de comprender, apoyar y sustentar durante todo este proceso. Porque ha estado a mi lado.

Gracias a todas estas personas por formar parte de mi vida.

DEPARTAMENTO DE DIDÁCTICA DE LA EDUCACIÓN FÍSICA, PLÁSTICA Y MUSICAL

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