SYSTEMATIC REVIEW OF THE EVIDENCE OF INTEROCEPTIVE AWARENESS IN PERFORMERS

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ABSTRACT

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Interoception is the conscious awareness of internal sensations coming from autonomic responses of the body including inputs such as visceral sensations, heart rate, sensations of tight muscles, etc. Those sensations are experienced due to the autonomic nervous system that is in charge of controlling and regulating bodily functions and cannot be manipulated intentionally. Previous research on interoception in performers has shown that a relationship exists between our inner bodily sensations and emotional experiences, and furthermore, between our energy management and decision making, which are fundamental aspects of optimal performance. The aim of this study was to summarize the available evidence of the effects of body awareness on an interoceptive level in performers.

The study comprises of a literature search on interoception and its relationship with performance. The search was done using the following databases: PubMed, SPORTDiscus and PsycINFO. To ensure validity and quality, the reviews' inclusion criteria were determined by solely including papers that have focused on body awareness, interoception, and healthy performers. The papers were required to be peer-reviewed journals and were searched in both English and Spanish. The exclusion criterion was applied to papers that were related to different components of interoception but involved body awareness. These included studies on proprioception, body image, self-image and medical treatment.

After removing duplicates a total of 543 articles were screened. This left only 12 articles which met the inclusion criteria. Interestingly, with regards the design of the reviewed studies, solely one paper used an experimental design out of 12. Also present was one phenomenological study, whereas ten exploratory designs were found. The results indicated that interoception is linked with significant areas of the brain that facilitate attentional control, emotion regulation, and awareness. Furthermore, studies have shown that the working memory is an important tool in cognitive processing, focus attention and decision making. Studies have concluded that the neurological basis of elite performers has better activation of the insula than non-elite athletes.

In conclusion, present results offer important insights into the developments of the interoception and performance fields. It is paramount to understand the differences between elite performers and novice counterparts in regards to the perception of bodily symptoms. However, it is still unclear to whether or not there is a way to practice and become more interoceptively aware or not. Suggestions for future research should continue with the unification of the terminology associated with interoception. Additionally, there is a need to conduct experimental randomized control trials focusing on athletes, evaluating the perception of inner bodily signals across different sport modalities. Furthermore, exploring these concepts in the field of exercise would not only benefit young people in facilitating more attractive methods of activity promotion, but also amongst obese or sedentary populations.

Keywords: *Performance, body awareness, attention, interoception, inner sensations*

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1 INTRODUCTION

There is a need to understand what characterizes top level performers. Previous research has associated emotional experiences and bodily symptoms as key to exceptional athletic performance (Robazza, Pellizari, & Hanin, 2004), and it is common knowledge that elite athletes possess different physical and mental features. Consequently, many researchers agree that it is of utmost importance to understand peak performances which will in turn facilitate the development of knowledge about the differences between experts and amateurs, for instance, understanding the neural basis (Sherlin, Larson & Sherlin, 2013; Harung Travis, Pensgaard, Boes, Cook-Greuter & Daley, 2011). Understanding the psychological aspects of elite performance will aid in enhancing and generating the integration of body and mind. This means that specific areas of the brain involved in peak experiences and advanced moral reasoning, lead one to experience heightened cognitive processes such as decision making and attention which are characteristics of top performers.

The first theory of body sensations was developed in 1884 by James-Lang, where it was proposed that visceral information (i.e., inner sensations) or interoception, is linked with emotional experiences. In other words, the perception of somatovisceral activation has a crucial influence in emotional experiences (Barret, Quigley, Bliss-Moreau, & Aronson, 2004). Due to the ability of the human being to perceive bodily sensations, one has the capacity to feel emotion (Pollatos, Gramann, & Schandry, 2007). It is of utmost importance to understand that interoception is a characteristic of body awareness, equivalent to proprioception, however, they are treated differently in the literature due to their distinctive aims and functionality (Craig, 2014).

James-Lang’s controversial assumption of emotions, inspired the development of a theoretical approach, ‘the somatic marker theory’, in which Damasio (1994) stated that the perception of bodily sensations has an impact on emotions and especially in decision making generating activation on the structure of the brain (e.g., insula, somatosensory cortices, cingulate, thalamus, brainstem nuclei, hypothalamus, and basal forebrain) (Craig, 2014; Pollatos, Gramann, & Schandry, 2007). Additionally, Damasio (1994) proposed with his somatic marker theory that automatic information received from the body due to a particular learned stimulus send signs to the brain that it is interpreted as a feeling state which could guide behaviour.

Moreover, the somatic marker can be performed unconsciously. This means that a person can make decisions ‘consciously’, but the brain ‘unconsciously’ is able to anticipate bodily changes and answer to an external stimulus before it happens. So in the anticipation process of an action the somatic marker hypothesis shows, unconsciously, possibilities either dangerous or favourable from which decisions are made (Craig, 2014; Damasio, Everitt, & Bishop, 1996; Damasio, 1994). This process is entitled “as if” by Damasio. Consequently, following this theoretical path we could say that the behaviour of an individual is influenced by body sensations that are represented in emotional experiences or subjective feelings. Supporting this idea, it has been stated that, the way in which one can experience feelings is due to a behavioural component, making feelings an outcome of behaviour (Laird, 2007).

Moving from the previous theory into the practice of sports, running or long distance races, attentional strategies such as association and dissociation have gained research attention since Morgan and Pollock (1977) found that top level marathoners used cognitive strategies during their race. These cognitive strategies are aimed to focus on inner sensations, for instance: pain, breathing and fatigue, that will help them to adjust their performance or last longer in the race avoiding injury. Conversely, dissociative strategies are those that athletes use to distract their thoughts with what is actually happening at the moment and normally the focus of attention is external of bodily sensations (Longman, Hutchinson, Stock, & Wells, 2014). However, the study of the awareness of bodily sensations and its relation with behaviour and emotions in performance have not been studied in depth. Consequently, acquiring attentional regulation training could be significant towards finding effective strategies to enhance body awareness (Mehling et al., 2012). Therefore, attentional strategies or emotion regulation interventions could prove essential in the study of this construct.

This paper will attempt to clarify a few concepts from different fields of behavioural and cognitive psychology as well as neuropsychology which are simultaneously used in sport and exercise psychology related to body awareness and interoception. However, as the terms and definitions of these topics are very similar there is not a unified language and could result in misleading information in this important interdisciplinary field (Garfinkel, Seth, Barret, Suzuki, & Critchley, 2015).

1.1 Conceptualization of Interoception

The perception of body signals has been studied in different fields, primarily in the medical and psychological (Mehling et al., 2011). Additionally, there are several definitions of body awareness. For instance, Mehling and colleagues (2011) define body awareness as, "the subjective, phenomenological aspect of proprioception and interoception that enters conscious awareness, and is modifiable by mental processes including attention, interpretation, appraisal, beliefs, memories, conditioning, attitudes and affect" (p.1). In contrast, Baas, Beery, Allen, Wizer and Wagoner (2004) state that it is the "ability to recognize subtle body cues and identify the physiological manifestations" (p.33). Therefore, it can be concluded that most authors recognize that body awareness is the perception of inner sensations and that it can be researched from different perspectives, however, according to Emanuelsen, Drew and Köteles (2015) the actual term of body awareness varies from author and is usually defined as interoceptive sensitivity. Additionally, in 1932, a neurophysiologist, Charles Sherrington, was awarded with the Nobel price, who introduced and distinguished the word interoception from proprioception for indicating these inner sensations but especially the ones that come from the viscera (Craig, 2014). This term has helped to differentiate some aspect of body awareness. In other words interoception are those signals that people can perceive from internal organs or viscera (Barret, Quigley, Bliss-Moreau, & Aronson, 2004).

Likewise, it is necessarily to understand for this review, that interoception is a different concept from the other systems that make up part of the bigger group of body awareness such as proprioception, exteroception, etc., where the former is the conscious perception of muscle, tendons and joints in relation with body position, movement and balance (Garfinkel, Seth, Barret, Suzuki, & Critchley, 2015; Fonseca & Bianca, 2014; Craig, 2014; Mehling et al., 2009). In contrast, exteroception is conceptualized as the sensations that are due to the signals that come from outside the body. Furthermore, another concept termed sensory information also exists, that has been classified in three different groups from the 5 traditional senses, which are: sensory information from vision and audition named teloreception, information coming from taste and smell called chemoreceptors, sensory input from temperature termed thermoreceptors and lastly, nociception is referred to when motoric reflexes are activated due to any physical damage or threat (Craig, 2002, 2014). Even though Sherrington conceptually classified these sensory inputs and proposed that nociception and thermoreception are features of exteroception, Craig (2014) found that the sensory receptors of the skin which have small-diameter axons are important for homeostatic functions, and therefore they are involved in interoceptive processes such as change in flow and respiration.

Therefore, we can observe from the definitions that there are different levels and characteristics of body awareness where we suggest that this construct could be evaluated individually in order to gain a better and clearer understanding. Conversely, papers have combined the study of body awareness exploring the perception of bodily sensation both externally and internally which have been linked with body image, satisfaction with physical appearance and eating disorders (Fonseca & Bianca, 2014; Mehling et al., 2009; Daubenmier, 2005). However, sometimes there is no clarification to what meaning of body awareness these studies are referring to specifically.

Even though the expression body awareness is used in many studies, it has been evident that different meanings have been adjusted accordingly to what the studies are looking for (Mehling et al., 2009), so, rarely a clear definition is provided (Bekker, Croon, Van Balkon, & Vermee, 2008; Haugstad et al., 2006), thus a better conceptualization is needed (Mehling et al., 2011; Mehling et al., 2009). Some of the different definitions of body awareness are depicted in Table 1.

Therefore, the meaning of body awareness for this paper is limited to the internal sensations from the body; those sensations that are better identified as “interoception” (Mehling et al., 2011; Mehling et al., 2009; Craig, 2002). Additionally, Craig (2002) expressed that well-being, energy levels and stress levels, mood and disposition can be described as how we perceive our body which goes along with the James-Lang theory of emotion. In the nineteenth century, it was translated that the feelings coming from the body are referring also to how well a person can feel emotionally. The German word for this is “gemeingefühl” which means “common sensation” (p. 2).

Table 1 Definition by author and year of body awareness throughout the years

AUTHOR/YEAR	BODY AWARENESS DEFINITION
Baas et al., 2004	Ability to recognize subtle body cues and identify the physiological manifestations
Craig, 2002, 2003a	Conscious attention of bodily sensations coming from internal or external functions
Mehling et al., 2011	Conscious awareness of aspects of proprioception and interoception which can be alterable by mental processes
Pollatos et al., 2007	Attention towards inner sensations of the body, such as, ones' heartbeat
Tsakiris et al., 2006	The conscious experience of the sense of agency and body ownership, which help to understand the position of a part of the body in relation to the space, better known as proprioception

1.2 Interoception and Neural Basis

Many studies have researched the influence of exercise in the brain and have presented interesting findings in the changes of brain activity and structure (Brümmer, Schneider, Abel, Vogt, & Strüder, 2011). These results on brain activity indicate that it can be greatly influential in athletes´ performances and subsequently any other activity that requires a display of skills in other domains such as musicians and managers (Thompson, Steffert, Ros, Leach, Gruzelier, 2008; Harung, & Travis, 2012). Brain activity can be studied or measured by using functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), and electroencephalography (EEG). In order to understand why and how those neuroimaging methods have been linked to performance, it is necessary to clarify how the basic procedures work.

Since the last decade many studies have explored brain activity through electroencephalography (EEG) measurements in athletes in which findings indicate strong correlations of high brain activity and top performance (Baumeister, Reinecke, Liesen, Weiss, 2008; Harung, Travis, Pensgaard, Boes, Cook-Greuter, Daley, 2011; Chuang, Huang,

& Hung, 2013; Sherlin, Larson, Sherlin, 2013). Therefore, there is a need for further studies that are able to support the findings and possibly investigate the mental skills that athletes could use to improve the areas of the brain that are directly involved in successful performance. Park et al. (2015) argued that even though the EEG technique is still in a beginning state, it possesses a number of limitations which leaves some authors reluctant in adopting brain imaging techniques as a method to develop better athletes (Walsh, 2014). Emerging methods such as mobile techniques will provide specialists with the capacity to move out of the laboratory and into real sport situations.

Electroencephalography (EEG) is a non-invasive method which is comprised of electrical signals that are transmitted from scalp electrodes to an amplifier and filtration in order to be able to read the microscopic signals on a computer which can be processed as continuous data. The electrical activity is captured due to a stimulus presentation or in some cases a behavioural task displays by the athlete or performer. Although EEG is a tool that has been used in sports for many years, it has crucial limitations as it holds poor spatial resolution of the specific areas of the brain involved in the neural activity. In contrast, EEG provides high temporal resolution that captures quick execution of motor movements, cognitive and sensory mechanisms fundamental in performances (Park, Fairweather, & Donaldson, 2015). In addition to the early limitations mentioned, when studying the data obtained, this tends to be contaminated by artefacts due to the body movements. These artefacts (muscle potential, sweating, electrode movement, etc.) are of non-cerebral origin, therefore, there are authors who can speculate this as the reason to why there are not a vast number of studies in sport science using the EEG recorder (Thompson, Steffert, Ros, Leach, & Gruzeiler, 2008). However, there are still researchers who believe in the practicality of this method to identify the neural mechanisms of sport performance and the inclusion of EEG and neurofeedback training as a way to modify behaviour or performance (Park, Fairweather, & Donaldson, 2015; Landers et al., 1991).

The EEG technique is used to look at the frequency of brainwaves, which are generated by electrical information which neurons use to communicate with each other. These electrical information or pulses are divided and described as bandwidths which are distinguished by their characteristics within 4 electrical levels. The slower waves have been classified as delta (5-3 Hz) and are identified with sleep. The theta waves (3-8 Hz) have been linked with task complexity and focus attention. For example, Baumeister et al. (2008)

studied the cortical activity of skilled golfers and found that trained golfers perform with an increased frontal-midline theta power in comparison with novices, which means a higher focused attention during the task in hand, an important tool towards peak performance. In addition, the theta waves are involved with learning and such memory processes as vivid imagery, intuition and conscious awareness. The next category is the alpha waves (8-12 Hz) and they are associated with being in the present moment. These waves have been researched extensively in the sport context (Park, Fairweather, & Donaldson, 2015) helping in overall mental coordination, calmness and alertness which are important in the homeostatic processes of the body. According to Thompson et al. (2008), EEG-biofeedback training aims, through this cortical area, to improve athletes` performance through enhancing their ability to remain focused. Additionally, researchers have shown that the training of alpha power provides athletes with a balance point of remaining calm and alert at the same time, which provides a very useful tool for any environmental or behavioural changes during any situation in a game (Harung et al. 2011). Likewise, the fourth waves are the beta (12-38 Hz), which are the most activated waves and are engaged in mental processes when the brain is aroused and active. These waves dominate the normal awake state of consciousness, during which the attention is directed towards cognitive tasks.

Studies on EEG have been conducted since the 50s`and the first investigation was in a pre-post study of the electro-cortical activity (Ravina, 1952) and the second one was a cross-sectional study (Busse, 1952) identified the differences between healthy adult professional boxers who had suffered head injuries. As a result of further studies with the use of electrical activity techniques in boxing and the repercussions of fighting sports on brain injuries, it facilitated the alteration of boxing rules (Kaste et al., 1982). Additionally, many studies have been carried out in the field of pre-task cognitive activity under the convenient conditions of shooting sports for EEG recording. The application of this method has facilitated investigators in finding differences between experts and novices and predictors of optimal performance (Baumeister, Reinecke, Liesen, & Weiss, 2008; Chuang, Huang, & Hung, 2013; Sherlin, Larson, & Sherlin, 2013).

Progressing to interoceptive studies, some authors have carried out experiments with EEG techniques exploring the relationship between the interoceptive ability through an interoceptive accuracy method (e.g. heartbeat task) with both subjective emotional experience and processing of emotional pictures (Herbert, Pollatos, & Schandry, 2007). This particular study aimed to replicate and extended findings by Pollatos and colleagues (2005) that the good heartbeat perceivers correlate with greater self-rated arousal for emotional pictures and slow wave amplitudes.

Another brain imaging technique that has been used in sport studies is the magnetoencephalography (MEG). This technique in comparison to EEG, records the magnetic fields that the brain produces naturally from the electrical activity. This technique is very innovative and widely used in clinical settings due to its higher resolution in comparison to the functional magnetic resonance imaging (fMRI) technique, as MEG provides data every 1 ms or less. Additionally, it provides clearer reading information of the skull and scalp than EEG (Kutcher et al., 2013).

MEG is a very sensitive tool that detects any magnetic information, therefore the data obtained from this technique could be full of noises. To counteract this effect, the device is located inside of a magnetically shielded room to avoid any kind of noises coming from the outside (Proudfoot, Woolrich, Nobre, & Turner, 2014). Also in Proudfoot et al., (2014) it is mentioned that stimulus presentations or external devices that remain in the shielded room must be electromagnetically noiseless as the MEG scanner can easily capture their signals. Moreover, subjects will be seated underneath a helmet which will be placed as close as possible to the subject’s head, and in the meantime with the shielded room’s door closed, electromagnetic activity will be recorded where experimental tasks and external stimulus or presentations can be performed (Proudfoot et al., 2014).

However, there are a series of aspects that could produce artefacts or interference to the data collected as this device is very sensitive to movements of the head, eyes, body and even cardiac activity. Therefore, is advised that participants avoid any type of head or body movement, unless the protocol of the research require these types of procedures. Also, accessories or products made by metal such as metal zippers, dental amalgam, jewellery, etc., generate electromagnetic information that will be shown in the data if it was not removed before measurements or taken into consideration (Proudfoot, Woolrich, Nobre, & Turner, 2014).

The MEG approach of recording and measuring brain activity can be nowadays easily applied to different domains extending its application from clinical settings. Consequently, some studies have directed the use of MEG recording towards athletes, sports and war-fighters, for instance, investigating behavioural, structural and physiological consequences of brain injuries and concussions (e.g., Tormenti et al., 2012; Kutcher et al., 2013). Additionally, other studies have focused on the study of structural and neuronal basis of athletes and activities related to sports looking for the brain activity in specific areas of the brain with regards anticipation and reaction time tasks (e.g., Endo, Kato, Kizuka, & Takeda, 2006; Tzagarakis, West, & Pellizzer, 2015). There are still many other areas in the field of sports and performance that can be greatly benefited from brain imaging techniques and even more when techniques such as the MEG is providing unique and complete results. A clear example of what was mentioned previously is that there are different approaches in sport and performance that can be studied throughout EEG and MEG, such as the use of imagery for enhancing performance (Thompson, Steffert, Ros, Leach & Gruzelier, 2008). Additionally, in neuroscience, studies have facilitated the creation of imagery models such as the PETTLEP (Physical, Environment, Task, Timing, Learning, Emotion, and Perspective) (Holmes, & Collins, 2001), in which they have shown a strong impact on athletes' performance by using the PETTLEP model rather than other imagery techniques previously created that do not have the support of neuroscience (Smith, Wright, & Cantwell, 2008).

Studies of athletes have shown that there are differences in how people perceive information, sensations and emotional experiences (e.g., Breivik, 1997; Hall, & Davies, 1991). More specifically, in relation to body awareness Hanin (2011) suggests that the body represents different physiological changes or signals that are individually distinct from person to person, such as: breathing, sweating, muscular tension, visceral functioning and other reactions. When individuals are exposed to negative emotions or dysfunctional states they experience other reactions such as anxiety, and exhaustion (Robazza et al., 2012).

Additionally, it has seen that brain imaging techniques are essential to understand how the body and brain works under specific conditions and why top level performers are better than average performers (Harung & Travis, 2012). Particularly, authors have been looking for explanations within theories of emotions and self-perception of bodily responses (e.g. Bechara et al., 2000; Damasio,1994,1999; Schachter & Singer, 1962) and to further study the brain throughout the already mentioned EEG, MEG and other methods in an effort to get closer to the understanding of the brain and behaviour.

One additional brain imaging method that has been used for the study of brain activity in performers is the functional magnetic resonance imaging or functional MRI. This technology is used to measure brain activity by looking at the relationship between blood flow and neuronal metabolism (Kutcher et al., 2013). There have been a few studies using fMRI in athletes (e.g., Ptito, Chen, & Johnston, 2007; Slobounov, Zhang, Ray, Johnson, & Sebastianelli, 2010) and according to Ptito and colleagues (2007), mild traumatic brain injury consequences have an important impact on the functionality of the person rather than on the structure. Consequently, utilizing functional brain imaging techniques in the study of concussions has proven invaluable in providing a more thorough insight than other techniques, such as, structural fMRI, that can provide mainly spatial information.

In order to create a clearer understanding into how mental processes and body signals work in one's body and what measures, such as fMRI, MEG and EEG, are looking for in the brain, it is necessary to indicate how the basic functioning of the brain works.

Consequently, the peripheral nervous system (PNS) is comprehended by two systems the somatic nervous system that controls all the skeletal muscles and body and the autonomic nervous system, which controls all those functions that the body cannot control voluntarily, such as; intestine, glands, blood vessels, heartbeat, etc. The latter is the system that interoception focuses on, as inner sensations are located in those functions that one is not able to control. While at the same time, the autonomic nervous system has two functions in energy management, expenditure and creation, throughout the sympathetic and parasympathetic functions accordingly. As stated by Craig (2014) this energy management is explained by the human homeostatic processes providing subjective feelings through interoceptive mechanisms as a way to evaluate the energy use that afterwards will be manifested in a form of behaviour.

The autonomic nervous system, which is capable of functioning independently, involves the parasympathetic structure already mentioned, which activates the left Anterior Insular (AI) and its function is to bring in energy by processes like rest and relaxation of the body. On the other hand, the sympathetic structure is linked with the right AI, which is the expenditure action or arousal like pain, fear, anger, etc. These sides collaborate with each other to facilitate a tuned homeostatic process, therefore, while one side speeds up the other side slows down (Craig, 2002; 2005; 2009). Additionally, the anterior insula (AI) is activated during homeostatic processes controlled by the autonomic activity. According to (Craig, 2005), emotions are associated with the asymmetry in energy management, thus the right hemisphere of the brain is linked with emotional arousal and the left with positive emotional feelings.

Modern neuroscience is in a privileged position at the moment, as there is more technology available that allows researchers to explore in depth how the brain works and the influence of cognitive and behavioural processes. Medford & Critchley (2010) proposed that the associated action between both the anterior insular cortex (AIC) and the anterior cingulate cortex (ACC) provides possible answers to how subjective experiences are originated from the sensory inputs and how this information influences affect, cognition and behaviour.

Activation in the ACC and the AIC have been shown in different studies of emotional processing, attention, self-recognition, facilitation of autonomic responses, etc. Some of these studies have found conjoined activation between both structures and some others show separate activation (Craig, 2009; Medford & Critchley, 2010). Consequently, it can be expressed that these areas of the brain are involved in tasks that direct the attention towards induced emotion and the generation of autonomic responses (Medford & Critchley, 2010; Lane, 2008). Furthermore, with these findings about the function of the ACC and AIC, Craig (2009) suggested that the cooperation of these regions of the brain can be found in the neural basis of self-awareness, which provides activity linked to ‘awareness of the moment’.

In summary, understanding the mechanism of the areas of the brain that are involved in emotional processes, energy management, interoception and bodily sensations, allows researchers interested in the field of neuroscience and interoception to investigate closely the interaction of the previous variables already mentioned with regards the specific areas of the brain providing more accurate and objective ways to measure interoception.

1.3 Measurement of interoception

Interoception has been measured with questionnaires and self-report methods, therefore, with the assumption that emotional processes are followed by bodily sensations or visceral perception from the autonomic nervous system, a heartbeat perception task was developed to measure more accurately visceral information from the body (Barret, Quigley, Bliss-Moreau, & Aronson, 2004; Schandry, 1981). The terms interoception, interoceptive sensitivity and interoceptive awareness have been used simultaneously without regard for their specific individual meanings providing a unified use of the construct. Thus, researchers have worked to clarify the terminology in order to differentiate measures from objective and subjective aspects (Garfinkel, Seth, Barret, Suzuki, & Critchley, 2015) (see Table 2 for a summary of the proposed methods).

Consequently, Garfinkel and colleagues (2015) classified the methods used to assess interoceptive ability in three dimensions: interoceptive accuracy, interoceptive sensibility and interoceptive awareness. In order to unify and clarify the language, the term interoceptive sensitivity has now been termed interoceptive accuracy which understands the behavioural measures that provide objective information of the interoceptive ability of individuals. This method usually involves a heartbeat task where subjects have to count their number of beats during a certain period of time. This is known as heartbeat tracking. Additionally, a different paradigm is used to assess heartbeat accuracy. This is achieved through the identification of an individuals' heartbeat synchrony. This is named as "Heartbeat Discrimination" (Schandry, 1981; Garfinkel et al., 2015). The second dimension is a subjective measure that authors have divided into two aspects; through self-report questionnaires to understand the difference in the interoceptive ability within subjects and a measure to find the perception of individuals' confidence about their inner sensations (i.e. confidence in interoceptive accuracy). These subjective measures are classified in the dimension of "interoceptive sensibility".

Table 2 Proposed terminology and methodology of assessing interoception (adapted from Garfinkel & Critchley, 2013)

Dimension	**Description**	**Methodology of assessment**
Interoceptive Accuracy	Objective measure (identifying internal sensations)	Behavioural tasks (e.g., Heartbeat tasks)
Interoceptive Sensibility	Subjective measure (determining self-belief and engagement)	Self-report measures and questionnaires (e.g., average of confidence and Multidimensional Assessment of Interoceptive Awareness)
Interoceptive Awareness	Metacognitive Awareness of the behavioural tasks (Interoceptive accuracy)	Interoceptive accuracy and self-assessment of confidence of the behavioural task

Nonetheless, self-report measures have proved that they are not accurate at representing objectively inner sensations, rather they tell what subjects think about how good their perception of inner sensation is (Schandry, 1981). Additionally, subjects can misread or misinterpret the information obtained from their bodies as this information is not automatically interpreted as feelings. Furthermore, there are differences in the perception of somatovisceral states in various situations, for instance, people are more body sensitive during exercise than others during rest (Barret, Quigley, Bliss-Moreau, & Aronson, 2004). Finally, in order to improve the accuracy of the measurements, using a combination of objective measures (i.e. interoceptive accuracy methods) and obtaining an awareness in an individuals' confidence in performing the task is necessary. This process determines the metacognitive process of the interoceptive ability which was suggested as "interoceptive awareness" (Garfinkel et al., 2015). Consequently, there is a gap in our knowledge about how to define and categorize interoception, also, this term has been scarcely used in performance and based on general research of interoception, it is assumed that inner sensations could have an important role for athletes' performances. Therefore, it is essential to summarize the previous knowledge of interoception in different forms of performance.

2 PURPOSE

The purpose of this systematic review is to summarize the available evidence on the effects of body awareness on an interoceptive level in performers. The aim of the study is to answer the following research question: what is the evidence of the use of interoceptive ability in performance, such as, athletes, exercisers, meditators, war fighters?

3 METHODS

3.1 Search strategy

The search process started in March 2015 and it was concluded in April 2016. The research strategy examined the following databases: PubMed, SPORTDiscus and PsycINFO. The selected databases were chosen as a result of analysing the research areas of their publications with the aim of obtaining mostly peer-reviewed papers related with interoception and performance. Additionally, in order to ascertain high quality and credible information, the review performed a hand search strategy by reading the reference list of retrieved articles and relevant reviews.

In regards with the keywords for the search procedure, different combinations of the following terms were used in PubMed and SPORTDiscus: Body awareness; Interoceptive Awareness; Interoception; Interoceptive Sensibility; Emotional Experience; Bodily Signals; Visceral Sensation; Introception and Optimal Performance; Optimal performers; Elite athlete; Performance; Athlete; Competitive Athlete; Performer; Performance Enhancement; Professional Athlete; Top Level Athlete. Additionally, for PsychINFO, the same terms were searched but we used truncations due to the settings of this database which work differently. We pursued this by searching plurals and variations of the words, and also we added an extra (AND) with the following terms: Sport*, Athlete*, Performer*, Runner*. The limiters were the same for the three databases; Peer Review, Journal Article, Academic Journal, Abstract, Free Full Text, Full Text, Humans, English, Spanish.

3.2 Inclusion criteria

The selection of articles was refined to those where the aim had any association with body awareness from an interoceptive perspective (bodily sensations, interoceptive awareness, sensibility, accuracy). Furthermore, the participants included in the studies needed to be a form of performer i.e., athletes, dancers, war-fighters, exercisers, etc. Additionally, those participants were required to be healthy subjects, unless the case of sport injuries were accepted, also Spanish and English papers were included in the search strategy and lastly, selected studies had to be published in a peer-reviewed journal (see Table 3).

3.3 Exclusion criteria

Studies were excluded when abstracts were without the full text available and not published in a peer-reviewed journal. The study report had to contain adequate information about the protocol. Additionally, during the first phase of data collection, at abstract level, the papers that explored proprioception, body image, self-image were excluded at the beginning. Even though those studies are somewhat a form of body awareness, due to the definition of interoception and the aim of the study which was clearly stated. Therefore, they had to be removed from the final pool of articles. Additionally, papers that described the subject type as linked with mental health, clinical studies and/or medical treatment in their respective abstracts were excluded as well. Lastly, at full text level, papers were removed from the table of articles when the aim of the study was not linked with the subject of interoception.

Table 3 Inclusion/Exclusion Criteria

Inclusion	**Exclusion**

• Peer reviewed studies
• English or Spanish
• Performers: Athletes
    o Dancers
    o War-fighters
    o Actors
    o Singers
    o Business
    o Meditators
    o Exercisers
• Body awareness studies:
    o Interoception
    o Bodily sensations
    o Paying attention to the body
• Healthy subjects or sport Injuries
• Interoceptive measures:
    o Heartbeat
    o Breathing
	• Other related Body Awareness studies:
	Proprioception
	Body Image
	Self-Image
	Nutrition
	• Clinical studies
	Medical treatment

3.4 Data extraction

Data was identified after having examined the most appropriate databases for the search, keywords to use, time span, language and most importantly the clarification of definitions to use for body awareness and performers, as those concepts differ considerably from authors and fields.

The first step was the screening at abstract level. Therefore, once all articles at this phase were extracted from the three data bases, the titles and abstracts were transferred to Refworks, which is an online reference library, to check for duplicates. Subsequently, all articles were collected without duplicates and imported to a word document to assess them according to the inclusion criteria. During this screening a small table was designed and placed bellow each abstract with two categories; participants and main topic. This strategy allowed us to select articles that fitted the general criteria established and were marked with "YES", "NOT" and/or a "?". "YES" meant that the article fits the criteria to some extent. "NO" suggested that the article does not fit the criteria in that category and only one "no" was necessary to reject the article. Finally, the question mark "?" meant that the title and abstract did not provide enough information to determine whether the article was suitable or not with regards the criteria for the specified category.

In order to simplify the selection of articles, a colour coding was used as follows; Yellow articles were marked when more information was needed, as the abstract did not provide enough information to define whether the participants and main topic fitted with what the study was looking for, thus, a full text analysis was required. The green colour meant that from the abstract analysis the paper probably fitted with the criteria and will pass to the full-text level. However, the red colour meant that the article did not have any relation with the aim of the study and therefore, we excluded those articles.

Consequently, articles coloured with green and yellow were arranged in order from 1 to 64, which is the final number of articles in the full-text level. Next, all 64 full articles were extracted and saved to start the intensive reading. Additionally, a table was created to chart the data with the variables that provided us with the most important information towards answering the research question. Some of those segments are as follows; aim, participants, hypothesis, design, and findings. Furthermore, this data charting as a form of table allowed us to gather all the necessary information from the articles, and also we were able to apply the colour system, which provided a systematic and effective approach in completion of the data collection.

The papers which proved difficult in determining whether they should be included or excluded in the final review were checked multiple times before the final decision was made. Ultimately to determine the final papers that were to be included, the aims of the papers were analysed thoroughly through the set criterion.

4 RESULTS

During the identification phase 648 articles were recorded from the three different databases and hand searching. This number was reduced from duplicates to 543 papers available to start the first screening phase. The title and abstract level of the screening generated a reduction of the pool of articles to 65 eligible, so that, following the inclusion/exclusion criteria a total of 478 articles were removed due to insignificant topics for the study including such as; proprioception, body image or general body awareness. Furthermore, the subjects were non-healthy subjects, non-athletes or performers, such as war-fighters, meditators or similar. After this first screening at abstract level, those 65 papers were assessed to a full-text analysis stage using the inclusion/exclusion criteria by reading them thoroughly. Consequently, 53 papers were excluded for different reasons, for instance; lack of information, medical treatment topics, some of the papers were conference papers, or leading articles. Lastly, papers with aims providing insufficient information or giving priority to body awareness relating to interoception or bodily sensations were excluded as well. Therefore, a total of 12 papers met the inclusion criteria and were included in the final review, leaving us with (N=1) qualitative study (e.g., Phillippe & Seiler, 2005) and 11 quantitative studies (see Figure 1). A further analysis was performed with the 53 articles excluded from the full-text phase. This was done by selecting the articles that were marked with the yellow colour, although none of them were ultimately included as their respective aims were not fully related with interoception. However, due to the importance of their results and discussion, 6 of those papers were taken into consideration while writing the discussion section of the present review. Amongst all, two papers were published between 1980 and 1996, three papers between 2005 and 2008, and 7 between 2010 and 2015.

4.1 Summary of Results

Interestingly, with regards the design of the reviewed studies, solely one paper used an experimental design out of 12 (Daniels & Landers, 1981) to investigate autonomic functions (i.e., heart rate, breathing) while performing a rifle shooting task. Also present was one phenomenological study (Phillippe & Seiler, 2005) which analysed the use of dissociative and associative strategies, specifically the interoceptive sensations such as; muscular tension, levels of laxity, heart rate, muscular pain, etc., on endurance athletes (e.g., runners, swimmers, cyclists) across genders during competition. This paper used structured interview guides based on a previous study from the same authors in 2003, in which athletes were asked to recall thoughts of past competitions especially when they had to manage pain during their races.

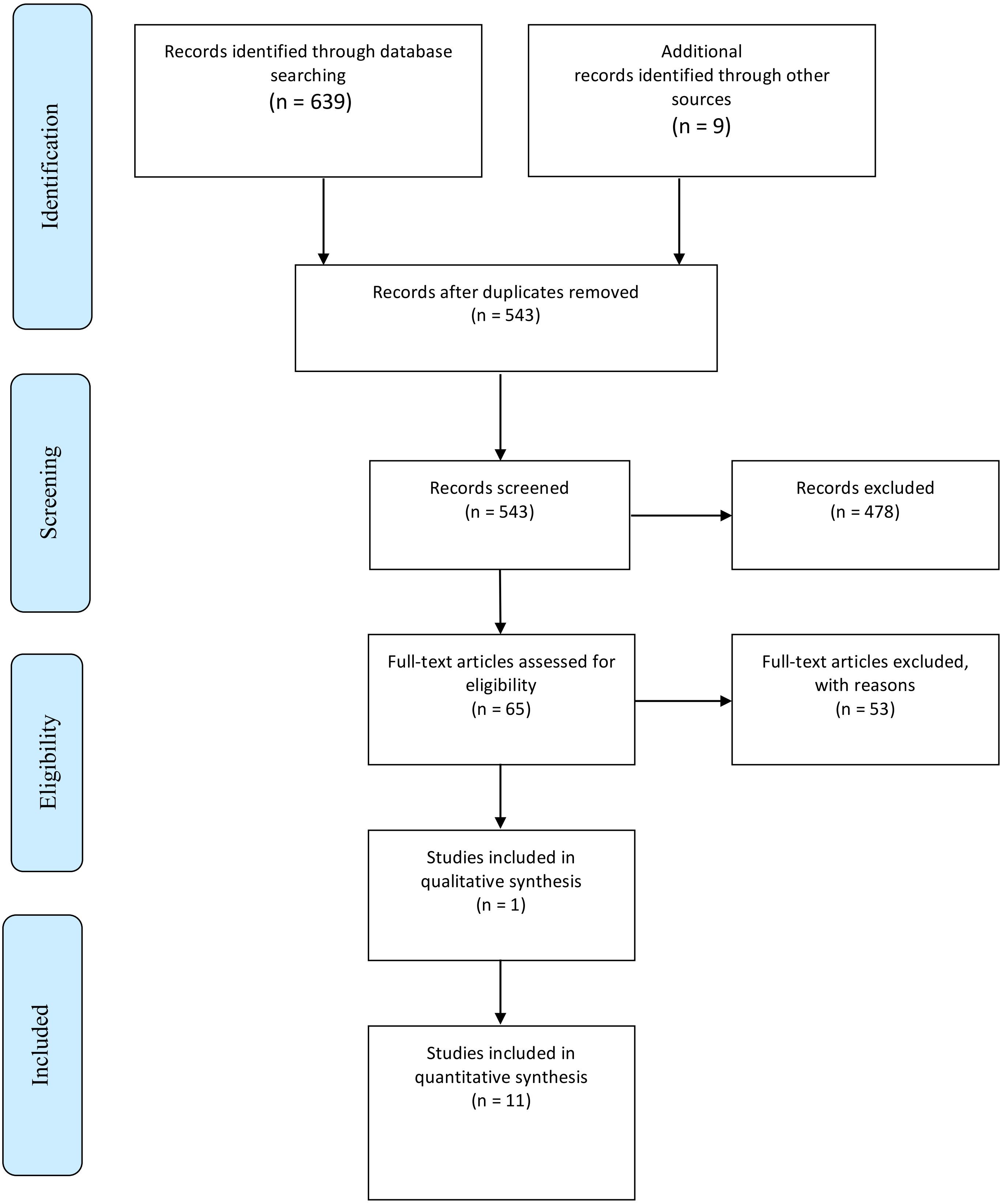
Ten exploratory designs were selected for this review in which four used a well-known heartbeat task to assess interoceptive accuracy (Georgiou et al., 2015; Melloni et al., 2013; Khalsa et al., 2008; Herbert, Ulbrich & Schandry, 2007), and two papers used respiratory tasks (i.e., respiratory load task, non-hypercapnia inspiratory breathing load) in order to assess interoceptive accuracy from another perspective in examining inner sensations (Daubenmier, Sze, Kerr, Kemeny & Mehling, 2013; Paulus et al., 2012). Another design used neuronal assessments through fMRI and questionnaires to detect any relationship between changes in the brain and emotions on elite adventure racers (Thom et al., 2014). A similar study was conducted by Paulus et al. (2010), that examined differences in the brain activation of Navy SEALs and a control group with regards an emotion face-processing task. Also, another study on Navy SEALs aimed to demonstrate the capacity of adaptation to an anticipatory stressor in correlation with higher activation in specific areas of the brain involved in emotional processes such as the insula (Simmons et al., 2012). Lastly, an article from Tammen (1996) examined the pace of long and middle distance runners through a flat track graded exercise test measuring maximum oxygen consumption and blood lactate.

4.2 Interoception assessment

4.2.1 Interoceptive Accuracy

Four studies were found (Georgiou et al., 2015; Melloni, et al., 2013; Khalsa et al., 2008; Herbert, Ulbrich, & Schandry, 2007) that have used different behavioural tasks to detect subjects' body sensations throughout autonomic functions like the heart (see Table 4). The most recent paper in this review by Georgiou and colleagues (2015) explored the relationship between interoceptive sensitivity, which is named by Garfinkel et al. (2015) as interoceptive accuracy. With regards to physical activity, authors used one of the most common measures of cardiac sensitivity, the Schandry paradigm (1981), a 'mental tracking method'. This behavioural task of perceiving ones' heartbeat has been proved to be reliable (Schandry, 1981; Mussgay et al., 1999). Additionally, a previous study in 2007 by Herbert, Ulbrich and Schandry, investigated the interaction between physical load and interoceptive sensitivity. The measurement used in this study performed the same protocol of the heartbeat detection task used by Garfinkel et al. (2015).

Figure 1 PRISMA Flow Diagram of screening process.



Moreover, there are other protocols for heartbeat detection that have been used on performers, such as meditation (Melloni et al., 2013; Khalsa et al., 2008). The former study used a keyboard where subjects needed to tap a key whilst being in a comfortable position during different conditions (motor-control, intero-pre, feedback condition, intero-post). Consequently, subjects were asked to follow the heartbeat of another person. Afterwards, they were required to follow their own heartbeat without feedback, then they had to follow it with an auditory feedback and lastly, they were given the same task without any auditory feedback. The aim of this study was to compare the interoceptive sensitivity among different levels of expertise in meditation. In a study conducted by Khalsa et al. (2008), their aim was to investigate the effects of two types of meditation on interoceptive sensitivity. This study used two techniques to assess interoception. The first task was denominated pulse detection familiarization, where subjects had to take their pulse from their non-dominant wrist and identify whether a tone, which was playing at the same time, was synchronized with their actual pulse or not. The second task was a heartbeat detection task where participants were asked to identify their heartbeat while the tone was playing, and without taking their pulse they had to respond whether the tone was in synchrony or not.

The studies conducted in physical activity settings with children (Georgiou et al., 2015; Herbert, Pollatos, & Schandry, 2007) indicated that by providing ways to improve the awareness of inner sensations, people could understand and apply strategies that facilitate the regulation of behaviour, which would lead them to more efficient methods of self-control in everyday physical and mental loads. Furthermore, two papers have performed respiratory assessments to evaluate interoceptive accuracy in meditators (Daubenmier, Sze, Kerr, Kemeny & Mehling, 2013) and to analyse neural and behavioural processing of elite athletes (Paulus et al., 2012).

Measuring conscious awareness of inner sensations has been done by respiratory tasks. Daubenmier and colleagues (2013) carried out an exploratory study with mindfulness meditators and non-meditators analysing the hypothesis that experienced meditators are better at acknowledging respiratory sensations than non-meditators. The respiratory tasks used in this study began with a detection task where participants were asked to breath normally for five minutes while they were attached to a mouthpiece and reading a magazine. This was used as a baseline for air flow and to help the participant in getting used to the breathing device. After, the resistive loads were presented several times and subjects needed to press a hand-held push button when they perceived a resistive load. Then, using the same methodology, a load discrimination task was implemented where subjects were asked to evaluate the resistive loads by using a keyboard measuring from “0” to “5”, the former being no resistance and the latter being the largest load condition. Following, a new procedure was used for this study which is called the “respiratory tracking task” which measures mindful attention to respiratory perception over time. This task was divided into two parts, the first part was a non-distractive period and the second part was a distractive period. Meditators and non-meditators were informed to track their breath rhythm for five minutes by using a slider, which shows both phase and depth of breath. After this procedure the level of the task was increased by combining it with an audio-visual distraction condition. Also four different emotional film clips were presented for two minutes each whilst they were performing the same previous task. There was a five-minute break between each task.

Table 4 Interoceptive accuracy studies using heartbeat behavioural tasks

Study	Participants	Interoceptive task	Findings
Georgiou et al. (2015)	N= 70 Children (3th to 4th Grade)	• Heartbeat perception task • Physical activity	• Differences among students within the interoceptive task. • The greater physical fitness level, the more interoceptive accuracy among children was found.
Melloni et al. (2013)	N= 10 (Long-term meditators) N= 9 (Short-term meditators) N= 10 (Meditators)	• Heartbeat detection task	• No differences between the groups within the interoceptive accuracy task.
Khalsa et al. (2008)	N= 17 (Kundalini Meditators) N= 13 (Tibetan Buddhist meditators) N= 17 (Non-meditators)	• Heartbeat detection task	• No differences in the interoceptive accuracy within the groups.
Herbert, Ulbrich, & Schandry (2007)	N=34 (University students)	• Heartbeat perception task • Physical activity	• Good heartbeat perceivers covered a significantly shorter distance than poor heartbeat perceivers.

Another approach used to measure interoception through respiratory methods was carried out by Paulus and colleagues (2012) where elite adventure racers and healthy volunteers performed a respiratory resistance load continuous task (see Table 5). Participants were asked to breathe through a hose which ultimately made their breathing more difficult as time passed. During the continuous task, subjects were asked to score their experience from 16 different dimensions of sensations and feelings on a scale of "not at all" to "extremely" at the end of every trial. The overall task was segmented into three parts, the first one was the baseline condition, where the participants executed the continuous performance task. Secondly, an anticipation condition was assessed by asking the participants to press a button according to the specific direction or sign. For example, if on the screen there was an arrow pointing towards the left direction, then the participant had to press the left button as fast as possible, but not before the signal is shown on the screen. This condition measured accuracy and response latency in order to examine anticipation and stimulus presentation. The background of the presentation helped to anticipate the imminent lack of breathing load. Lastly, another stimulus condition was presented where the background colour behind the arrow signals was yellow indicating a 25% likelihood that the participant is experiencing 40 seconds of limited breathing.

Table 5 Interoceptive accuracy studies using respiration behavioural tasks and biofeedback

Study	**Participants**	**Interoceptive task**	**Findings**
Daubenmier, Sze, Kerr, Kemeny, & Mehling, (2013)	N= 18 (Meditators) N= 16 (Non-meditators)	• Respiratory load detection task • Respiratory load discrimination task • Respiratory tracking task	• No differences among groups on the detection and discrimination tasks. • Meditators group showed greater accuracy on the non-distracted tracking task.
Paulus et al. (2012)	N= 10 (Elite adventure racers) N= 11 (Healthy volunteers)	• Inspiratory breathing load	• Racers showed greater accuracy on the interoceptive task during the continuous performance task.
Daniels & Landers (1981)	N= 8 (High level junior shooters)	• Heart rate (HR) • Respiratory strain gauge	• Shooters possess greater awareness of their autonomic functioning.

An early study (Daniels & Landers, 1981) explored the effects of biofeedback on experienced shooters' performance based on previous studies (Wilkinson, Landers, & Daniels, 1981; Daniels, Landers, Hatfield, & Wilkinson, in press) which with the combination of the 'autonomic perception questionnaire' (Mandler & Mandler, 1958), heart rate and respiration of the autonomic responses was researched (see Table 5). The heart rate was measured by placing electrodes on participants' skin and controlled by a monitor. The respiration was monitored by using a strain gauge positioned on the abdominal area. Additionally, physiological measures were recorded in order to check cardiac and respiratory patterns so that a proper intervention could be applied due to the data collected from the baseline. Consequently, ten different physiological measures were taken from athletes during the baseline session (80-shot pre-test), some which included; heart rate before breath hold, heart rate after shot, length of breath hold, etc. After the baseline, a 7-Item interview was used to understand athletes' psychological experiences during their performance in the pre-test trial. Analysis of the psychophysiological measures and performance were made and adjusted to a posterior biofeedback intervention with shooters during 5 sessions.

4.2.2 Interoceptive Sensibility

The present review obtained 5 papers that used different questionnaires to measure anxiety, psychological factors, perception of effort, personality and emotional states (Thom et al., 2014; Daubenmier, Sze, Kerr, Kemeny & Mehling, 2013; Melloni et al., 2013; Paulus et al., 2012; Tammen, 1996). However, some of those self-report measures are not directly linked with the aim of this review. Two papers were found to have strong associations with the awareness of internal sensations through self-perceptions or self-reports of the performers. One of the mentioned studies (Daubenmier, Sze, Kerr, Kemeny & Mehling, 2013), in conjunction with a respiratory task for analysing the interoceptive accuracy of subjects, used three scales to assess body awareness. For example, the 12 items of the Body Awareness sub-scale of the Body Connection Scale (BCS) was applied in order to measure the attention of inner sensations that demonstrate bodily and emotional states (Price & Thompson, 2007) (see Table 6). The Body Responsiveness Questionnaire (BRQ) was performed by meditators and non-meditators to measure whether there is any difference in the consolidation of body sensations (e.g., heartbeat, respiration) in daily life decision-making or behaviours. Lastly, a Breath Awareness Scale was developed by authors with six items in which two of them can be found in the Multidimensional Assessment of Interoceptive Awareness (Mehling et al., 2012) (see Table 6). The second significant paper (Tammen, 1996) found to have relevant information related to interoception on an interoceptive sensibility level used a mental readiness form with runners to measure thoughts and feelings after each trial. Consequently, runners were requested to score items like body

Table 6 Interoceptive Sensibility: Body Awareness Self-Report Questionnaires

Author	Instrument		Construct	Assessment system	Body Awareness
Daubenmier et al. 2013	Body Connection Scale (BCS; Price & Thompson, 2007)	12 items	Conscious attention to internal sensations indicating bodily and emotional states (i.e., anger, stress, and peacefulness)	7-point scale (1=never to - 7=always)	YES
	Body Responsiveness Questionnaire (BRQ; Daubenmier, 2005)		Integrate body sensations into conscious awareness to guide decision making and behaviour to avoid suppression or impulsive reaction	7-point scale (1=not at all true about me to - 7=very true about me)	YES
	Body Responsiveness Questionnaire (BRQ; Daubenmier, 2005)	Importance subscale	The importance of using interoceptive information to regulate behaviour and self-awareness	7-point scale (1=not at all true about me to - 7=very true about me)	YES
	Body Responsiveness Questionnaire (BRQ; Daubenmier, 2005)	Perceived Disconnection subscale	Perceived disconnection between psychological and bodily states	7-point scale (1=not at all true about me to - 7=very true about me)	YES
	Breath Awareness Scale (Daubenmier, 2013)		Conscious attention of breathing processes	7-point scale (1=never to - 7=always)	YES
	The State - Trait Anxiety Inventory (Spielberger, Corsuch, & Lushene, 1970)		Assessing feelings of state anxiety, trait anxiety	4-point scale 1=almost never - 4=almost always (trait)/ 1=not at all - 4=very much (state)	NO

Table 6 (Continued)

Author	Instrument	Construct	Assessment system	Body awareness
Tammen, (1996)	Mental Readiness Form (Krane, 1994; Murphy, Greenspan, Jowdy, & Tammen, 1989)	Assess thoughts and feelings after each run	10 cm line by pointing to a place align the line that matched the cognition	YES
	Perceived exertion scale (Borg scale; Borg, 1978)	Assess the perceived work load	15-point scale 6=very very light - 20= very very hard	NO

sensations from ‘relax’ to ‘tense’ or whether they were aware of their body sensations or distracting thoughts. Additionally, the 15-items of the perceived exertion of effort proposed by Borg, 1978 (taken from Borg, 1982) was applied to record the perceived work load of participants.

4.2.3 Neural basis of Interoception

Brain imaging techniques have been used in studies of body awareness and interoception to understand better the neural basis and processes. Four studies (see Table 7) of the present review have used brain techniques to provide a better understanding of how the brain of elite athletes perform in different situations (Thom et al., 2014; Paulus et al., 2012; Simmons et al., 2012; Paulus et al., 2010).

The earliest study out of these four papers was carried out by Paulus & Colleagues (2010) which implemented an emotion face-processing task where war-fighters were the subjects who needed to select one picture from the bottom of the screen that showed the same emotion as the target picture at the top of the screen. These target faces were six consecutive trials of angry, fearful, or happy emotions. At the same time an fMRI technique was performed to explore neural processing differences on elite war fighters in comparison with control subjects.

Additionally, a publication from the same author two years later (2012) used the same brain imaging technique (fMRI) and proposed to explore neural processes involved in performing body predictor errors, i.e. insula cortex on elite adventure racers. The fMRI scanning was performed during the baseline condition of the study for about nine seconds on average, the same time was used for the anticipation condition and around 12 seconds for the post-stimulus condition. Besides looking for the activation of specific regions of the brain, authors where assessing accuracy and latency of the different conditions of the task. Consequently, it is appropriate to associate the integration of different areas of the insula cortex, and top-down information from other parts of the brain with performance enhancement (Paulus et al., 2012.

Table 7 Neural Processing Studies Found in Interoception

Study	Participants	Brain imaging	Findings
Thom et al 2014	N=10 (Elite adventure racers) N=12 (Healthy volunteers)	• fMRI	• Activation in the right insula, left amygdala and dorsal anterior cingulate was shown by racers. • In comparison with the control group an attenuated activation of the right medial prefrontal cortex was presented.
Paulus et al, 2012	N=10 (Elite adventure racers) N=11 (Healthy volunteers)	• Non-Hypercapnic Inspiratory Breathing Load	• Racers showed great activation of bilateral insula, dorsolateral prefrontal cortex and anterior cingulate. • While the breathing load and the post condition it was showed attenuated activation on the right insula cortex.
Simmons, et al., 2012	N=10 (Navy SEALs•) N=11 (Healthy male volunteers)	• fMRI	• Elite warriors demonstrated right anterior insula activation while affective set-shifting. • Attenuated insula activation to negative image.
Paulus et al, 2010	(N=11) Navy Sea, Air, and Land Forces (SEALs) (N=23) Male volunteers	• fMRI while emotion face processing task.	• Elite warriors showed activation in the right-sided insula and attenuated in the left side. • War fighter showed bilateral insula activation to angry target faces. • Lower neural activation to happy target faces and nonthreat stimulus.

Simmons & colleagues (2012) carried out a study continuing with the previous work mentioned on war-fighters by Paulus et al. (2010). These Navy SEALs are considered to be elite performers and it is believed that they possess similar neural activation as elite athletes. Therefore, in this study authors performed an anticipatory task to explore the adaptation to stressful situations. They explored this through functional magnetic resonance imaging (fMRI) of the insula, which is involved in interoceptive functions of the body. The present paper is helping with the development of a neural model of elite performance.

Lastly, the earlier paper by Thom et al., (2014) explored the activation of the insula while performing an emotion-face process to find out how elite adventure racers adjusted their internal emotional states. The study explored different areas of the brain, such as, the 'anterior insula' and 'anterior cingulate' which were founded in previous studies to have a relation in processes of interoception, subjective feelings and others (Paulus et al., 2010).

4.3 Outcomes

The papers analysed allowed us to make three different groups of subject characteristics that we can relate to performance in different ways. Firstly, there were 5 articles published using athletes (Thom et al., 2014; Paulus et al., 2012; Philippe & Seiler, 2005; Tammen, 1996; Daniels & Landers, 1981). Then, we decided to include war-fighters as part of the athletes group as it has been shown that there are similarities in their abilities in performance (Paulus et al., 2010). Among the war-fighters group, two papers have used ‘Navy Sea, Air, Land forces’ (SEALs) (Simmons et al., 2012; Paulus et al., 2010). The second group is referred to as the paradigm of meditators from different types, for example; ‘Kundalini Meditation’, ‘Tibetan Buddhist’, etc. We obtained three studies for this category; Daubenmier, Sze, Kerr, Kemeny, & Mehling (2013), Melloni et al. (2013) and Khalsa et al. (2008). Lastly, the group of physical activity and exercise, presenting two exploratory designs, (Georgiou et al., 2015; Herbert, Ulbrich & Schandry, 2007).

4.3.1 Outcomes of Interoceptive Studies within Sports

The earliest study of this review used a small sample of four Olympic shooters where their self-awareness of autonomic functions of the body were investigated (e.g. heartbeat, breathing) as an important characteristic of performance (Daniels & Landers, 1981). Authors affirmed that the results of the experiment helped athletes to recognize the impact of self-supervision of those autonomic functions on their performance. Thus the biofeedback system was used as a tool that allowed shooters to modify their behaviours in shooting according to the information given by their heart rate and/or breathing when an imbalance or dysregulation was noticed. Finally, authors suggested that the use of biofeedback training has great advantages for closed-skill sports through the use of psychophysiological tools.

A different study by Phillippe and Seiler (2005), researched the gender differences on cognitive strategies between runners, swimmers and cyclists. The hypothesis of this study was that males will score higher on the use of associative strategies during performance, for instance male athletes will pay more attention to inner sensations (i.e., heart rate, pain tolerance, muscular tension) and will use that to adjust their pace or race strategy. It was concluded that men use more associative strategies than females. According to Phillippe and Seiler (2005), supporting previous studies on pain-tolerance suggested that “women are culturally conditioned to avoid pain; tolerance of pain is indicative of strength and endurance, more synonymous with masculinity" (p. 444). Consequently, women are more likely to use dissociative strategies than men.

Continuing with cognitive and coping strategies, different papers have used endurance sports to analyse this phenomenon such as an early paper by Tammen (1996), which explored associative strategies of eight middle and long distance runners, through self-report questionnaires, a perceived exertion scale and thought debriefing, while performing a maximum oxygen consumption Vo2max Protocol. Interestingly, runners showed more associative strategies when they were performing at a higher pace of running or higher effort of exercise. It was mentioned by the athletes that it was easier for them to recognize their bodily sensations (i.e., breathing, muscular tension) when they were pushing up to their maximal physical effort whereas low loads of effort or easy paces would make them turn their attention towards dissociative functions, such as exterior situations, paying attention to the researchers, etc.

Two studies have used the same study subjects for their research (Thom et al., 2014; Paulus et al., 2012) which consisted of ten adventure racers (6 males, 4 females), however, their comparison groups were different and the aims differ as well. In 2014, Thom et al. aimed to conclude whether being an elite performer has any association with an overall emotion processing effect or the goals of the team determine the emotional processing efficiency. Whereas, Paulus and colleagues' (2012) aimed to examine whether elite athletes show attenuated neural processing of aversive interoceptive stimulation in the insular cortex by testing the behavioural and neural processing response of elite athletes during an aversive interoceptive non-hypercapnic breathing load.

In Paulus et al. (2012) the neural basis was assessed and behavioural findings were considered. Consequently, adventure racers performed better than the comparison subjects at challenging interoceptive stimulations on the continuous task demonstrating that elite athletes perform greater under challenging situations. Furthermore, Thom and colleagues (2014) is consistent with previous finding showed in this review that elite athletes pay close attention to bodily sensations (Philippe & Seiler, 2005). Most importantly these results tell us that elite athletes process emotions differently and even more when they are part of a team as they may interpret others' emotional information according to decision making.

Additionally, Simmons et al., (2012) and Paulus et al., (2010), have carried out different studies with war-fighters and more specifically with Navy SEALs who have successfully completed a strenuous military training and can be seen as elite performers with elite characteristics such as; mental toughness, achievement motivation, physical strength and endurance, emotional stability and body functioning. These factors have been linked with neural processing and body functioning allowing a person to possess an optimal homeostatic system. Results from these studies have noted that specific areas of the brain, which have been explained previously along this paper, have had certain type of activation. For instance, the insular cortex has been seen as important for processes of interoceptive awareness and subjective feelings. Particularly studies have shown that these brain areas are linked with emotional face processing and the internal resources management, or energy expenditure to adapt in hostile environments (Simmons et al., 2012; Paulus et al., 2012; Paulus et al., 2010). In other words, brain areas adapt to situations where a person is out of their comfort zone, for example, subjects processed resources differently from controls when angry faces where shown during the task (Paulus et al., 2010).

These areas of the brain are associated with the behavioural and cognitive performance of the person in order to minimize body prediction error. They are therefore very important for decision making and success (Thom et al., 2014; Paulus et al., 2010). This was tested by the emotional face task where war-fighters looked at angry faces which may have activated a strong body prediction error signal that in a real scenario can be expressed as a critical decision that they have to make in order to obtain a positive outcome.

4.3.2 Outcomes of Interoceptive Studies within Meditation

Meditation has been linked to this study due to the increasing use of meditative techniques as a tool to enhance performance in different domains. More specifically, this paradigm has been involved as a tool to increase body awareness (Farb, Segal, & Anderson, 2013; Melloni et al., 2013; Mehling et al., 2009) and sport performance (Sappington & Longshore, 2015). Even though it is a growing field, authors have suggested more and in-depth studies into the feasibility of this construct on performance enhancement.

Daubenmier and colleagues (2013) examined the accuracy of interoceptive accuracy of mindfulness meditators against non-meditators through a respiratory load detection task.

This study produced interesting findings as interoceptive accuracy did not differ from non-meditators. Additionally, the respiration patterns were tracked so it was found that meditators have a slower respiration rate than the comparison group. However, during a distraction task where the meditators were expected to have greater scores in relation with the non-meditators, the results found were not statistically significant for the study. Therefore, the authors advise for further studies to obtain more subjects than in the present one (Table 5).

On the other hand, the same study found a negative correlation between interoceptive accuracy and interoceptive sensibility (i.e., self-report measures) and more importantly between anxiety levels and the meditators group. The opposite was found in the non-meditators group. Similar findings were shown in Melloni & colleagues (2013), where the anxiety levels of long term meditators were considerably lower than the control group (non-meditators). These are conflicting results due to other papers findings in which subjects with greater interoceptive accuracy having increased levels of anxiety (Daubenmier et al., 2013).

Furthermore, lower levels of anxiety in Long-Term Meditators (LTM) and depression in Short-Term Meditators (STM) in comparison with non-meditators can be explained through the skills that people can obtain from meditation in regards with stress, coping and emotion regulation competences (Melloni et al., 2013). Interestingly, this study was the first of its kind due to its' exploration into the influence of meditative practices in interoception and more specifically into heartbeat and the relationship with social cognition. Even though the protocol of cardiac interoceptive assessment in meditators was performed similar to other studies providing negative results, Melloni and colleagues (2013) noticed that the use of interoceptive accuracy measures with this population is probably not the most appropriate measure considering that breathing is one important focus of attention in meditation and also other body signals (Khalsa et al., 2008), rather than the heartbeat. Consequently, negative results were presented in studies of meditation and interoception where heartbeat tasks were used as the measure of interoceptive accuracy.

In the third study of performers, focusing on meditators, the aim was to analyse the effects of meditation practice on interoceptive awareness among two very well-known traditions in the United States, the Tibetan Buddhism and Kundalini yoga (Khalsa et al., 2008). The overall results contradicted the hypothesis that expert meditators would show better interoceptive accuracy than non-meditators, however, as mentioned previously, these negative findings could be due to the interoceptive detection task applied (i.e., heartbeat detection task).

Additionally, Khalsa and colleagues (2008) mentioned the possibility that a resting state is a condition that has an effect on the heartbeat task and the results of the interoceptive accuracy measures. Although it is known that visceral sensations are difficult to recognise for any individual, it is assumed that meditators can perceive autonomic sensations such as breathing or heartbeat easier than untrained individuals. This is assumed as whilst being in a resting state, meditators focus their attention on these sensations. However, this does not assure that meditators will perform better. It was found from Khalsa et al (2008), that there are no significant differences in the interoceptive accuracy task. Interestingly, meditators assessed the task as easier than the non-meditators and showed more confidence when rating a positive accuracy level in their own answers but both groups showed normal performance in the task.

4.3.3 Outcomes of Interoceptive Studies within Physical Activity

Many studies have observed the function of self-awareness in internal bodily sensations on self-regulation of exerted physical activity and the greater distribution of this physical effort on subjects who have high levels of cardiac accuracy (Georgiou et al., 2015; Herbert, Ulbrich & Schandry, 2007).

Consequently, a study carried out by Herbert, Ulbrich and Schandry (2007) explored how healthy subjects perform a 15-minute bicycle ergometer protocol. Authors found that when subjects were free to control their own cycling pace, those with good heartbeat accuracy were not able to cover the same distance as those with lesser interoceptive accuracy. However, it was indicated by authors that this can be explained as a good management of effort by the better heartbeat perceivers. Therefore, it can be assumed, that they possess a better understanding of their fatigue limits and bodily signals. Interestingly, it was found that good heartbeat perceivers engaged in less physical exertion than the poor heartbeat perceivers, although both groups experienced the same fatigue levels. Therefore, it can be said, that people who are more in tuned with their body sensations and their processes are able to activate regions of the brain which help the body to behave in a more self-regulated way or synchrony, depending on the physical needs of everyday life (Herbert, Ulbrich, & Schandry, 2007).

In another study Georgiou et al. (2015) examined the interaction between interoceptive sensitivity and physical activity where a 6-min run protocol was used to assess physical activity and a heartbeat perception task was used to assess interoceptive sensitivity, or as we named it in this review "accuracy". The subjects were 49 children and a subsample of 21, whose physical activity was measured on a daily basis by a multisensory device for a duration of five consecutive days. The results presented a positive correlation between interoception and physical fitness in the children, who are from 3rd and 4th grade classes. However, according to Georgiou and colleagues (2015), these findings do not support the evidence found in previous studies with healthy adults. Moreover, children who demonstrated a normal to increased BMI and a high fitness level possessed greater levels of interoceptive accuracy, whereas children with the normal to increased BMI characteristics and a low fitness level had a poor heartbeat accuracy.

In Herbert, Ulbrich, and Schandry (2007) children performed the cycling protocol at their own pace, in which findings correlated with a high interoceptive accuracy and a better self-control of their energy or effort. Furthermore, in Georgiou et al. (2015), children were asked to perform a 6-minute running test as fast as they could with the results indicating similarities in the sense that there are correlations between greater fitness levels and good heartbeat accuracy. Thus, there was a positive correlation between the "light daily physical activity task" and "interoceptive sensitivity", with which authors can conclude that physical activity can promote the ability to recognize inner sensations more accurately (Georgiou et al., 2015).

Assumptions were made by Georgiou et al. (2015) about children who are able to remain in harmony or in tune with their bodily sensations, indicating that this would facilitate a healthier development. Thus they would be able to self-regulate their daily physical load preventing extreme exhaustion and causing positive healthy behaviours which is of utmost importance in child development. Additionally, they affirmed that interoceptive sensitivity could be a key tool for the development of bodily signals, however, this assumption is still in discussion.

5 DISCUSSION

5.1 Interoception in Performance

The present study aimed to summarise the accessible evidence of the literature with regards to body awareness and performance, and more specifically in the field of interoception and/or bodily sensations. At the same time, the focus was to answer the research aim of this study on whether any evidence exists in the practice of interoception in performance.

Consequently, a total of 12 papers met the inclusion criteria, only one qualitative study and 11 quantitative studies were found to have any relation with interoception and performance. Among these 11 quantitative studies only one experimental research was carried out considerably early in 1981. The exploratory studies in this field have increased since then, however, further qualitative methodology research and quantitative randomized control trials are required as these methods help to validate previous findings and aid in the development of scientific research in the field of interoception in performance. Conversely, there has been a large body of research in the clinical and mental health field, with patients or subjects who have been linked with anxiety, pain, depression, and heightened body signals (Mehling, et al., 2009).

5.2 Traditional Strategies Used by Athletes and Exercisers

The current review classified subjects of obtained papers (e.g., athletes, war-fighters, exercises) into different groups of performers (e.g., athletes and exercisers). These subjects varied greatly ranging from navy SEALs to physically active university students, from high level junior shooters to children from 3rd to 4th grade who exercise. Even though these groups possessed enormous differences in terms of physical and mental characteristics, there was an interconnection with the way how they approached performance because all of them train different skills that were put into action by cognitive and/or bodily processes which have been associated with emotional responses that could be either functional or dysfunctional for the performer (Bertollo, Satarelli, & Robazza, 2009), and lead to a positive or negative outcome when talking about competitions.

Additionally, other cognitive processes are involved in the success of an elite performer such as cognitive strategies, but they are not the only ones who acquire these strategies. Also, young exercises who want to implement behaviour changes in their lives, for instance obese children, studies have demonstrated that the implementation of attentional distraction, or better known as dissociative strategies, has provided obese teenagers better results against their expectation as shown in De Bourdeaudhuij, Crombez, Deforche, Vinaimont, Debode, and Bouckaert, (2002). This study consisted of testing a fitness program in obese adolescents and children under the bases of attentional distraction strategies in running. Consequently, results showed that obese children and teens went over their predictions on the treadmill whilst running with their favourite pieces of music. These are very interesting findings on aerobic fitness and confirmed what was stated in 1977 by Morgan & Pollock about the attentional strategies used by elite marathoners who claimed to benefit from associative strategies in comparison with non-elite runners. Therefore, it can be said that elite performers benefit greatly from an adequate preparation that allows them to cope with obstacles, regulate emotions (Bertollo, Satarelli, & Robazza, 2009; Robazza & Bortoli, 1998) and more importantly understand their bodily sensations. Novice performers in any field, for example, artists, war-fighters, athletes, exercisers, and so on, could misperceive their body sensations of pain, tightness, warmth, fatigue, allowing the body to activate its security alert before it shuts down. This alert is interpreted as the person stops the exercise apparently due to exhaustion, but sometimes it could be as a result of misinterpretation of bodily signals. Thus, strategies that distract the mind are popularly used by the non-trained population as it seems to be easier to distract the attention that the body interprets.

It is clear that an athlete cannot stay 100% of the time focused and attentive, therefore, athletes need to combine dissociation and association strategies according to their needs, activities or sport modalities. A study conducted Robazza and Bortoli (1998) indicated that mental strategies are an idiosyncratic characteristic of athletes and accordingly some elite archers need to distract their attention between rounds by listening to music, talking to team mates or opponents in order to remain fully focused when they have to perform. Additionally, the results from the single randomized control trial (Daniels & Landers, 1981) suggested that world-class rifle shooters had greater levels of perception about autonomic functions. Additionally, the experiment supported the benefits of biofeedback when applied to shooters as it helped them to perceive important physiological patterns that they were not able to notice before using the self-monitoring system. Verifying this finding, Robazza and Bortoli (1998) claimed that these types of mental skills, like understanding when and how to use their attention and how to interpret their bodily signals, come with preparation and competitive experience.

Nonetheless, the body of literature has increased immensely since 1977 when Morgan & Pollock examined the psychological characteristics of elite distance runners and found out through interviews that elite runners read their body for the duration of their runs and associate the pain in order to adjust pace or effort when a critical situation is presented during their competition. This was the first time that the idea of using associative and dissociative strategies appeared. Consequently, the literature, in regards with this construct, has increased extensively so authors have used these terms to research athletes' relationship with attention, cognitive processes and strategies which sometimes creates a misuse of the terms as described by an early review in associative and dissociative strategies (Masters & Ogles, 1998).

5.3 Meditative strategies associated with interoception

Models and strategies (Farb, Segal, & Anderson, 2013; Bernier, Thienot, Codron, & Fournier, 2009) to promote a better understanding of ones' bodily sensations have flourished significantly during the last decade as it has been recognized to help in conjunction with physical and other psychological characteristics to promote emotional control, better performance, better coping strategies, etc., towards the achievement of peak performance. Recently meditative approaches such as mindfulness have been dominant in a variety of research in different domains, one of those being in the exploration of the effects of the mindfulness technique on interoception (i.e., inner sensations, body scan, pain) especially in health science. However, there is a need for more studies to research into the effects of this technique incorporating inner body sensations and performance. Although there have already been some exploratory studies conducted in sports reporting that athletes have mentioned awareness of bodily sensations, internal experiences and cognitive process of acceptance during flow (Baltzell, Caraballo, Chipman, & Hayden, 2014; Bernier, Thienot, Codron, & Fournier, 2009), it is necessary to focus more on qualitative resources that facilitate a unified theoretical background of performance and interoception.

Meditative techniques or techniques stemming from eastern cultures could be an initial step to expand the construct of body awareness at an interoceptive level in performance as it has not been explored so far. Recently, there has been papers published exploring different types of meditative approaches testing its effects on interoception on a neurological level, however, some of them are focused in clinical settings (Garfinkel, & Critchley, 2013). We assumed that this connection of interoception and neuroscience in medical practices is due to its profound use in health treatment studies (Nejad et al., 2014). A similar situation has occurred with mindfulness in that it has been a technique with curative purposes for anxiety, stress and other behaviours.

However, meditation and mindfulness have been widely researched in different fields. To the knowledge of the present review, three papers were found studying these ancient techniques and mindfulness in interoception. The assumption made by Melloni et al. (2013) and Khalsa et al. (2008) was that meditators would be better at perceiving their heartbeats than non-meditators, however both studies agreed that the interoceptive accuracy task through a heartbeat paradigm is not the most appropriate method in testing interoceptive sensations in meditators as the findings did not show any difference within the groups. Conversely, the first study testing mindfulness and interoception in 2013 by Daubenmier and colleagues used different paradigms to measure the autonomic sensations. A respiratory task was used where surprisingly there were no differences among the groups in the detection and discrimination task, though a greater accuracy it was shown in the distracted task. Additionally, the experienced meditators presented higher levels of confidence towards the interoceptive task performance as they judged the task as easy and with a positive result of their performance in comparison with their counterparts. It might be easily assumed that meditators are better at perceiving bodily sensations than non-meditators, and also they know or they think that they are good at it, but it has been shown that it is of utmost importance to apply the precise instrument to do so. Likewise, it is paramount to understand how they use that self-awareness, whether it is only an unconscious skill, or can it be activated for certain circumstances? Therefore, in order to figure out if meditative techniques can be used to train interoception and consequently used to facilitate the development of better performers, we must provide more scientific background to understand the influence of this construct in interoception and even on a neural bases level.

5.4 Metacognitive and Self Report Strategies in Interoception

In an effort to understand how performers perceive inner body sensations, researchers have used metacognitive strategies and interoceptive sensibility approaches, better known as self-report measures or questionnaires in body awareness and a few in interoception. In order to identify what has been done and how, Mehling et al. (2009) systematically reviewed the self-report measures used in body awareness studies in which 12 articles met the inclusion criteria. Articles associated with body image and self-image were removed due to the orientation of body awareness and specifically, interoception. Mehling and colleagues (2009) suggested that the terminology used for body awareness should be clarified as body awareness holds different dimensions and is not a unified characteristic. Furthermore, there is a need to develop questionnaires that can be used for both proprioception and interoception. These findings can be the reference point to acknowledge how researchers understand body awareness and how it is implemented in their studies.

Consequently, Mehling and colleagues (2009) argued that there is not a clear understanding of whether there are mind-body approaches that enhance body awareness. An interesting explanation could be the lack of focus in each element of body awareness separately rather than considering them as one big group. In contrast, as it was shown previously Garfinkel, Seth, Barret, Suzuki, and Critchley (2015) have worked to clarify the definitions of interoception reporting that in most instruments used to measure body awareness, there is not a coherent separation between dimensions, which means that there is a need to develop structural instruments targeting the different areas of body awareness.

Reporting the results of this review in regards with the questionnaires used by authors, only five papers were reported to use different self-report measurements of body awareness, anxiety, depression, sensations and others, and only two studies Daubenmier, Sze, Kerr, Kemeny, and Mehling (2013) and Tammen (1996) used measurements that specifically evaluated body awareness. Nevertheless, none of the questionnaires used in the two papers were part of the suggested instruments by Mehling et al. (2009) with strong psychometric characteristics. Supporting previous comments, it was concluded that there was not a single self-report, at the time of the self-report review in 2009, that was comprehensive and reliable in demonstrating their construct.

5.5 Future Research and Implications

Future research should begin with the unification of the terminology associated with interoception and the development of more systematic and clear measurements that could provide accurate knowledge into how interoception is perceived by subjects. Additionally, there has been a slight increase of exploratory research on interoception and performance and subsequently a lack of quantitative studies. Therefore, it is recommended to increase the body of literature on a quantitative level with the purpose to support further experimental studies. Furthermore, there is a need to conduct experimental randomized control trials focusing on athletes for instance, as the bodily signals could be different across modalities such as between team and individual sports and it would be interesting to see if any of these groups show a greater level of interoception and to what extent are they used in their performances. Using a brain activity technique could be essential in understanding and differentiating the neural basis. There have already been some developments in interoception and exercisers. Exploring more in this group would not only benefit young people in facilitating more attractive methods of activity promotion, but also amongst obese or sedentary populations. The results could benefit young athletes in understanding how to tune their bodies from a younger age and contribute to the learning of physical and psychological skills as the awareness of body signals stimulate cognitive and behavioural process occurring in the brain.

Finally, the continuous research of meditative techniques and other embodiment techniques could provide cooperation in the pursuit of practical elements that can be used to teach individuals to be more in tune and understand their bodily signals instead of misreading the body.

5.6 Limitations

The selection of the studies that fit the criteria was limited and special care was needed in the selection of articles according to the criteria of this study. Due to the lack of literature that defines the terms used in body awareness, a crucial factor that helped to select the articles for this systematic review was the understanding of body awareness and the distinction between its different characteristics.

6 CONCLUSIONS

It is understood from the results of the present review, that interoception could have an essential role in performance. It can therefore be assumed that by being more perceptive with ones' bodily sensations, which allows a person to be in tune with their bodily signals, it could lead to the efficient and more effective management of their energy which could prevent exhaustion in any mode of performance. However, it is still unclear to whether or not there is a way to practice and become more interoceptively aware or not. Even though there has been a poor quantity of papers in regards to interoception in performance, this review has helped to acknowledge that body signals have a strong relation with elite performers. Thus the 12 papers reviewed have demonstrated consistency with their results showing greater use of mental preparation and strategies than their counterparts. This provides a display of behaviours that only top level performers can demonstrate, and additionally the results indicated that the better a performer is at perceiving bodily signals, the higher the activation of specific areas in their brains. Consequently, these areas of the brain, the so called, 'Anterior Cingulate Cortex' and 'Anterior Insular' have an important role in interoception and performance as they are involved in the display of emotions, behaviour and the homeostatic structure of the body that can be seen as the "control button" of energy in the body. This is how elite athletes can be distinguished from their counterparts and classic sport psychology has to recognize these constructs in their contribution to an athletes' performance by comprehending how the brain and body function in unity. Many elements still need to be understood and expectedly there will always be questions to answer but with the combination of modern sport psychology models (e.g., mindfulness, meditative techniques, etc.), classic sport psychology approaches and the advancements in modern technology, the field will continue to develop rapidly.

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