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SENSORY ATTENUATION OF PAIN: THE ROLE OF THREAT

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Abstract English

The objective of this research is to investigate the phenomenon of sensory attenuation in response to painful stimuli and its association with movement, attention, and threat. While there exists a considerable body of knowledge regarding sensory attenuation for tactile stimuli during movement, its applicability to pain perception remains less understood due to the attention-captivating nature of pain signals. Additionally, extensive research has been conducted on the impact of pain on the body and the processes involved in pain relief; however, the influence of the motor command system on pain perception is still inadequately understood. Furthermore, the effects of directing attention and the role of threat in the attentional mechanism remain ambiguous. This investigation aims to explore the effects of movement preparation and execution on the sensory attenuation of pain, as well as the potential amplifying effect of threat on pain perception. To accomplish this, a total of 79 healthy participants were subjected to pain stimulus trials while performing either a hand movement or maintaining their hand in a static position. Specifically, participants executed a reaching movement with their right hand while keeping their left hand immobile. Following each trial, participants provided ratings indicating the perceived intensity of the pain stimulus experienced by each hand. Sensory attenuation was assessed using a measure known as the point of subjective equality. The participants were randomly assigned to either a threat or neutral condition. The findings of this study suggest that the experience of threat does not significantly impact the perception of pain. Furthermore, sensory attenuation was observed during movement execution, while no definitive evidence was found for sensory attenuation during movement preparation.

Abstract Nederlands

Het doel van deze studie is het onderzoeken van het fenomeen sensorische suppressie bij pijnlijke prikkels en de relatie met beweging, aandacht en dreiging. Hoewel er aanzienlijke kennis is over sensorische suppressie bij tactiele prikkels tijdens beweging, blijft de toepasbaarheid ervan op pijn minder duidelijk vanwege de signaalfunctie van pijnsignalen die automatisch aandacht trekken. Daarnaast is er uitgebreid onderzoek gedaan naar de impact van pijn op het lichaam en de processen van pijnverlichting, maar de invloed van het motor-commandosysteem op pijnperceptie blijft minder goed begrepen. Bovendien zijn de effecten van aandacht voor pijn en de rol van dreiging in het aandachtssysteem nog onduidelijk. Het onderzoek richt zich ook op de effecten van bewegingsvoorbereiding en -uitvoering op de sensorische attenuatie van pijn, evenals het mogelijke versterkende effect van dreiging op pijnperceptie. In totaal namen 79 gezonde deelnemers deel aan het onderzoek. De deelnemers werden willekeurig verdeeld in de dreigingsgroep of de neutrale groep. Pijnstimulatietesten werden uitgevoerd, waarbij de deelnemers gevraagd werd om hun hand te bewegen of niet te bewegen. Meer specifiek moesten ze afwisselend een grijpbeweging of geen beweging met hun rechterhand uitvoeren, terwijl hun linkerhand statisch bleef. Na elke test gaven de deelnemers aan hoe sterk ze de prikkel op elke hand waarnamen. Sensorische demping werd beoordeeld met behulp van een punt van subjectieve gelijkheid-maatregel. De bevindingen tonen aan dat dreiging geen significante invloed heeft op de perceptie van pijn. Bovendien werd sensorische suppressie waargenomen tijdens de bewegingsuitvoering, terwijl er geen bewijs werd gevonden voor sensorische suppressie bij de bewegingsvoorbereiding.

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Sensory attenuation by pain: the role of threat

Pain is a widespread phenomenon and is known worldwide. Even though it is a universal phenomenon, not everyone copes with it in the same way. Some people who experience pain just continue with their daily lives, while others experience a lot of discomfort and therefore avoid movement, which results in less pain. This difference in pain experience results from the fact that pain processing is not uniform. Pain processing is influenced by multiple factors. Such factors are for example attentional processes, motor processes and the impact of threat, which will all be discussed in this thesis. Before these topics will be discussed, pain in general will be discussed together with its effect on individuals and the environment.

Pain is defined to be "an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage" (International Association for Study of Pain, 1994). Within this definition, there are three important qualities of pain. First, pain has unique sensory and perceptual characteristics (Crombez & Eccleston, 1999), i.e. pain is different for everybody; it is a personal experience. Second, there is no absolute correspondence between pain and tissue damage. Third, pain is an unpleasant emotional experience (Crombez & Eccleston, 1999). For example, a feeling of pain can cause various emotions such as anger and sadness.

Pain is a universal challenge. Globally, about 30% of the population was reported to have chronic pain complaints (Drieskens et al., 2018). Looking specifically at the prevalence numbers of pain complaints in Belgium, a rather stable number was observed between 1997 and 2003 (23.0% to 24.3%), while after this the prevalence increased to 26.7% in 2018. These measurements were taken from people that were aged 15 years or older (Drieskens, Charafeddine & Van Der Heyden, 2018). When looking at the figures of chronic pain, we see that 23% of the Belgian population suffers from it. In Europe, it can be noted that it is slightly lower namely 19%, while worldwide the number is 30%. A possible explanation for these differences could be that the delineation of chronic pain in the different studies was not done in the same way. Another noteworthy fact is the socio-demographic difference: people with a lower degree report more experience of pain than people with a higher educational achievement (Drieskens et al., 2018). Furthermore, age has an influence on the reporting of pain. The older one gets; the more pain is reported. In the age group 15-24 years, 16.9% reported pain experience, which is low compared to the age group 75 years and older where the number is more than double namely 35,1%. Last, women report more pain compared to men experience over all age categories (Drieskens et al., 2018). About one third of the Belgian people who have pain complaints are limited in their daily life by this pain (Drieskens et al., 2018).

Pain is thus a universal challenge. Pain has a major impact on several social, economic and clinical areas Henschke, Kamper & Maher, 2015). Pain, especially chronic pain, places a heavy burden on the individual and the environment of the patient. It interferes with the quality of the patient's life. It often has an impact on daily life, which in turn has a negative influence on relationships and interactions. These influences lead to the perception of more pain (Henschke et al., 2015). In addition to the social difficulties, there is also the economic burden. There are high costs involved, some direct, f.e. that you cannot go to work because of pain, and some indirect, f.e. that you have to hire a housekeeper (Henschke et al., 2015). The financial impact on society is also considerable, since people with (chronic) pain use health care resources almost twice as much as people without these complaints (Henschke et al., 2015). In the research of Quatana, Campbell & Edwards (2009) it was estimated that 80% of doctor visits are due to pain. They also estimated a loss of US$100 billion based on healthcare costs and lost productivity (Quartana et al., 2009).

Throughout the years there has been a wide variety of scientific interpretations of pain. Those interpretations were often not similar to the present one. In the past, the dualistic approach of pain was the most accepted one. The dualistic viewpoint suggests that the body and the mind function separately and independently (Gatchel, Peng, Peters, Fuchs & Turk, 2007). Therefore, the dualistic approach focused on the sensory mechanism of pain, (i.e. external stimuli causing physical or mental pain), while other factors such as cognitive, affective and behavioral factors were not considered. Consequently, pain was seen as secondary to the physical symptoms. Therefore, the intensity of pain the patient experienced was linked to the magnitude of the tissue damage (Gatchel, et al., 2007). Another model that was widely used was the biomedical model. This was in line with the dualistic view, as pain was also only linked to either physical or mental symptoms. (Andrasik, Flor & Turk, 2005).

As mentioned, the dualistic approach views the body and mind as two separate entities, which is a line of thought that is nowadays considered incorrect (Gatchel et al., 2007). Currently, it is acknowledged that psychosocial factors, such as emotional stress, can affect the perception of symptoms, medical diseases and response to treatment (Gatchel et al., 2007). Another model is therefore widely used now, which does include these variables. This model is called the biopsychosocial model (*figure 1)*. The biopsychosocial model is a conceptual model that highlights the interactive processes between biological (i.e. genetics of a person), psychological (i.e. when one is depressed they may react different from someone who is not depressed) and social factors (i.e. a person's environment) in health and illness. The focus is on both disease and illness (Gatchel, 2004). Illness Is understood as a multifaceted interplay of biological, psychological, and social factors (Gatchel, 2004). Disease, on the other hand, is defined as an "objective biological event" characterized by the disruption of specific body structures or organ systems resulting from anatomical, pathological, or psychological changes (Turk & Monarch, 2002). In contrast to disease, illness is perceived as a "subjective experience of self-attribution" acknowledging the existence of disease. Illness, therefore pertains to how a sick individual and one's family members cope with, respond to, symptoms and disability (Gatchel, 2004). When looking specifically at pain, there may be concluded that this model views pain as the product of a complex interaction between biological, psychological and social variables. The diversity of the expression of pain can also be explained by this model, this can be explained by the social component, namely we learn a lot from observing other people (Andrasik et al., 2005). The biopsychosocial has been labelled as a fruitful and heuristic model (Andrasik et al., 2005). Furthermore, it is the most relevant for understanding and treating chronic pain (Gatchel,et al., 2007). Nowadays, the biopsychosocial model is applied for a wide variety of pathologies, such as (chronic) pain.

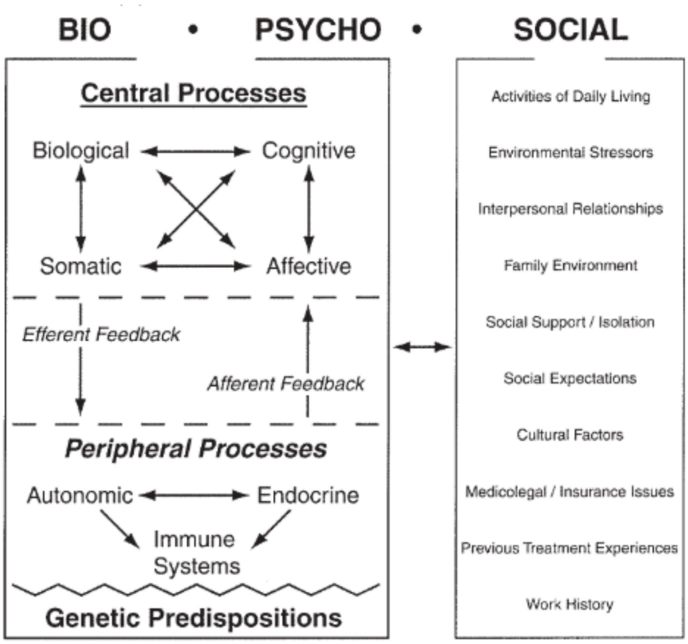


Figure 1. The biopsychosocial model is a conceptual model highlighting the biopsychosocial interactive process involved in heath and illness (Gatchel et al., 2007).

In addition to the biospyschosocial model, there is another model that provides a good representation of the current view of pain. Loeser (2000) formulated a general model, the model of Loeser *(figure 2)* that distinguishes four dimensions associated with pain: *nociception, pain, suffering and pain behaviour. Nociception* refers to the process of transferring information about potential tissue damage to the brain, while *pain* is the subjective perception of the tissue damage (Gatchel et al., 2007). The subjective perception is a result of the transduction, transmission and modulation of sensory information. The third dimension, *suffering,* is a consequence of physical or psychological threat to the integrity of being human (Cassel, 1982). Last, *pain behaviour* is the behaviour a person will adopt during or after experiencing pain, such as shouting, crying or becoming very quiet (Loeser, 2000). Similar to the biopsychosocial model, this model does not consider the mind and body as two separated factors (Loeser, 2000).

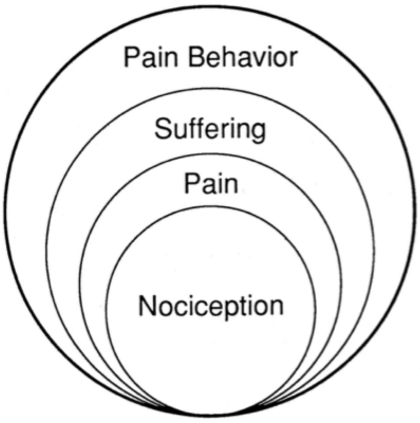


Figure 2. The model of Loeser, a representation of the universe of pain through four circles, each representing a component of pain (Loeser, 2000)

The phenomenon of pain is very broad and has many influences, as has been discussed in the previous paragraphs. A further distinction can be made between different types of pain. The conceptual model of Loeser (2000) provides a statement about three broad classes of pain: transient, acute and chronic. **Transient pain** is pain that passes rapidly and results from the activation of nociceptive transducers in the skin or other tissue (Loeser, 2000). This type of pain is omnipresent in everyday life and is rarely a reason to contact healthcare.

The second type of pain to be discussed by Loeser (2000) is **acute pain**. The most used definition of acute pain is “the normal predicted psychological response to an adverse chemical, thermal or mechanical stimulus, […] associated with surgery, trauma and acute illness” (Carr & Goudas, 1999). Acute pain is elicited by a physical injury and by the corresponding activation of the nociceptive transducers on the location of the injury. An injury is also characterised by changes of responses in the nociceptors and in the central and in the autonomic nervous system. When such an injury occurs it doesn’t overwhelm the reparative mechanism (the mechanism that helps repair the tissue damage/injury), it can heal without external medical help. However, external medical help can offer some advantages, such as pain reduction and facilitation of damaged tissue repair. Healing often takes from a few days to a few weeks. Pain that persists for several months is thus not included in this type of pain (Loeser, 2000).

The National Association for the Study of Pain defined **chronic pain** as pain that is present for more than three months (Hylands-White et al., 2017). Chronic pain is a persistent pain that is present for long after it has served a useful purpose, i.e. it is no longer a symptom of an injury or disease but it is an autonomous medical problem (Hylands-White et al., 2017). Chronic pain can also be described as a syndrome characterized by persistent factors, i.e. physical pain, disability, emotional disturbance and social isolation, these factors are all included in the biopsychosocial model, which is why this can explain chronic pain (Gatchel et al., 2007). The psychosocial aspects described by the biopsychosocial model *(figure 1)* involve both psychological (i.e. emotion, cognition and beliefs) and social factors (i.e. cultural norms and values, social network, socioeconomic status) (Crombez et al., 2012). Therefore, chronic pain is challenging both physically and mentally.

As discussed earlier, pain is subjective (i.e. some Individuals have a low pain threshold and are very sensitive to pain, while those with a high pain threshold are more tolerant to pain) and this can make it challenging for research. A distinction can be made between clinical pain and experimental pain. Clinical pain is naturally present. The patients cannot escape their pain, or the daily life situations associated with pain (den Hollander et al., 2015). While experimental pain is experienced during an experiment and is influenced by the researcher. Experimental pain only occurs in a highly controlled environment. Experimental pain can also be stopped at any time by the researcher (den Hollander et al., 2015)

In the previous paragraphs several aspects concerning pain have been discussed such as the influence of pain on the individual, on the social environment and on the economic burden, and the definition of pain. To better understand the experience of pain, there are some concepts to clarify it, one of them is protective behaviour. Protective behaviours do not result from pain itself, but from the personal perception of pain. According to research, two significant concepts can be identified related to this. First, the value one gives to this threat of pain depends on the context and on the individuals, even though pain has intrinsic threatening features. Second, protective responses may be beneficial in the short term, but have the potential to aggravate the problem in the long term. (Vlaeyen & Linton, 2012). Certain protective behaviours are usually observed while experiencing pain. Some responses are automatic, like quickly withdrawing from a harmful stimulus, while others can be performed deliberately, e.g. yelling or swearing when experiencing pain (Vlaeyen & Linton, 2012).

The first concept indicates that individual believes play a role in the experience of pain. This was also suggested by the research of Crombez, et al. (2012), which elaborates on the storage, exacerbation, reduction and maintenance of pain and suffering (Crombez, Eccleston, Van Damme, Vlaeyen & Karoly, 2012). It was however suggested that beliefs are strongly influenced by myths, which lead to false beliefs of pain. Most of these myths are related to the mistaken believes (i) that pain is a signal of tissue damage, with disability as an inevitable consequence, and (ii) that pain is something medical and can only be solved with medical treatment (Crombez et al., 2012). Previous research, namely (Gatchel et al., 2007) & (Van Damme, Crombez, Van Nieuwenborgh-De Wever, et al., 2008), already emphasised the importance of believes about pain and the role of disabling fear and avoidance. The Fear Avoidance model describes how people who experience acute pain, become trapped, and create a circle of chronic discomfort and suffering, resulting in chronic pain.

Figure 3. A schematic representation of the Fear avoidance model (Vlaeyen & Linton, 2012).

The essence of Fear Avoidance is the personal perception of pain. If one sees pain as non-threatening, people will return to day-to-day activities, usually after a period of reduced activity (Crombez et al., 2012). However, when one sees pain as threatening (e.g. when pain is misinterpreted as a signal of severe injury or disease beyond one’s control), a high level of fear of pain or injury is induced. The latter, pain related **catastrophising**, can be seen as a set of exaggerated and negative cognitive and emotional schemas expressed in response to actual or anticipated pain stimuli. Furthermore, catastrophising is explained as the tendency to increase the threat value of pain stimuli and to experience helplessness in the context of pain, and a relative inability to suppress pain-related thoughts in the run-up to, during or after a painful event (Quartana et al., 2009). What is additionally important to note is that pain catastrophising shares several significant variance with broader negative affect constructs such as depression, anxiety, worry and neuroticism (Quartana et al., 2009). Such catastrophic thinking causes a fear of movement, resulting in the avoidance of physical activities since they may aggravate the pain, which can have negative consequences such as slower healing of a strain (Crombez et al., 2012). In fact, many chronic pain patients struggle with pain catastrophizing and fear avoidance beliefs (i.e. through fear of pain, avoiding movement/activity) (Gatchel, et al., 2007).

Another important factor for potential negative consequences of pain is **hypervigilance**. First the concept of vigilance will be explained to clarify the concept hypervigilance (Crombez et al., 2005). The concept vigilance is used to refer to the ability of organisms to persevere their focus of attention and to stay alert to stimuli over an extended period of time (Davies & Parasuraman, 1982; Parasuraman, 1986). Vigilance or increased awareness of the possible sources of threat is often caused by high levels of fear of fear related thinking (Crombez & Eccleston, 1999). The mere threat of pain will facilitate the emergence of a pain-related stimulus. People who experience pain stimuli as extremely threatening and catastrophize, will be more sensitive to the effect of the threat of pain, which in turn facilitates the onset of pain (Crombez & Eccleston, 1999). This leads to hypervigilance which is the automatic selection of pain or pain-related information and suppressing other information in the environment (Aldrich et al., 2000). Pain is the main focus and can be distressing for the person experiencing it. Hypervigilance is driven by the fear system (Crombez et al., 2005). Vlaeyen and Linton (2000) presumed in their Fear-Avoidance model for low back pain that patient who fear injury are hypervigilant to pain, which results in avoidance behaviour. Two considerations are important for understanding hypervigilance to pain: (i) hypervigilance emerges when a person’s goal is related to avoidance and escape from pain., and (ii) hypervigilance is primarily thought to be automatic (Crombez et al., 2005). In short term, hypervigilance and avoidance do not appear to have any negative consequences. It can be considered to protect the body from further injury and to provide time for healing, but when one looks at the long-term consequences, it is considered dysfunctional and will cause more pain and suffering. Moreover, the suffering occurs not only physically, but it can also affect one mentally. The consequence of this suffering can result in a depressive mood and physical deconditioning (Crombez et al., 2012). Hypervigilance is a phenomenon based on attention. The patients experiencing pain have difficulties shifting attention, the main focus is pain and/or pain signals (Crombez et al., 2005).

In addition to the Fear-Avoidance model, it is noteworthy that attentional processes, play an equally important role. Furthermore, it can be established that attention also plays an important role in pain perception. The perception of pain is the outcome of a complex dynamic system. The system codes, transduces and processes nociceptive signals. The relation between nociceptive information and pain is mainly influenced by cognitive and affective factors (Tracey & Mantyh, 2007). Attention serves as a mechanism through which sensory elements are selectively processed, allowing individuals to become aware of specific stimuli related to pain (Legrain et al., 2009). It has been pushed forward as a mechanism to try and explain the perception of acute and chronic pain. It is especially important, considering the concept that people can start scanning the body for pain signals or injury (Crombez et al., 2005).

Attention is often captivated by the most noticeable stimuli in our environment. Salience refers to the extent to which a stimulus stands out from competing stimuli in terms of observable features (e.g. an eye catcher, pain, …). The selection of attention is not uniform across all information. Certain subjects hold greater significance and therefore take precedence over less important matters. For instance, studies have shown that fear plays a vital role in attention selection. Ohman, Flyk & Esteve (2001) conducted a study to determine if participants were more likely to detect fear relevant stimuli amidst fear-irrelevant stimuli. Fear irrelevant pictures consisted of flowers and mushrooms, while fear-relevant stimuli included spiders and snakes. The study concluded that participants were quicker at noticing fear-relevant stimuli compared to fear-irrelevant stimuli, indicating that fear has an influence on attention selection (Ohman et al., 2001). The selection of attention can be accomplished through various means. The study of Legrain's et al. (2009) examined two modes, namely the top down and bottom-up modes, these two modes operate in a fundamentally different way. Top-down selection involves intentional goal-orientated processes that that prioritizes relevant information for contemporaneous actions. This selection is achieved by sensitizing stimulus-specific neurons, namely by increasing the activity of neurons to relevant stimuli and reducing activity to irrelevant stimuli (Legrain et al., 2009). The prefrontal and parietal cortices are believed to play a role in this process (Corbetta & Shulman, 2002). It is still unclear which role the cortexes play concerning pain (Legrain et al., 2009). On the other hand, bottom-up selection refers to unintentional attention-capturing events driven by stimuli (Yantis, 2000). The perspective of bottom up aims to explain the ability of a subject to notice targets and the goal-triggered attentional processing largely through the sensory salience of the target and their capacity to trigger attentional processing by engaging higher cortical areas in a bottom up manner (i.e. from observing an object which is processed in the primary visual cortex to the temporal region to identify the object) (Sarter et al., 2001). Even though bottom up is unintentional, it is not fully automatic and can be influenced by top-down selection (Legrain et al., 2009).

Several behavioral studies have shown that pain decreases when attention is diverted from the nociceptive pain stimulus (Van Damme, Crombez, & Eccleston, 2008). Legrain, et al. (2005) conducted a study that not only explored early attentional operations but also examined how attention can involuntarily persist towards nociceptive events with a delayed latency. The study provided evidence for the interaction between bottom-up and top-down factors in directing attention towards or away from nociceptive events (Legrain et al., 2005). These results came about through EEG studies that showed that the amplitude of the P2 component of nociceptive evoked potentials decreases when participants perform a more demanding task, indicating the influence of attention on pain processing (Van Damme, Crombez, & Eccleston, 2008).

Hauck's et al. (2015) also investigated the relationship between pain and attention. Their experiment involved administering high and low pain stimuli randomly and examining the impact on attention. The study found that in the top-down mode, there was no difference in attentional capture between high and low pain stimuli. However, in the bottom-up mode, high pain stimuli attracted more attention compared to low pain stimuli (Hauck et al., 2015). Attention can be seen as a mechanism for the selection of information (Crombez & Eccleston, 1999).

Attention selection is dependent of intensity, novelty and the threat value (Crombez et al., 2005). Individuals don’t see or feel everything, but they see or feel the things that draw their attention (Crombez & Eccleston, 1999). Attention is therefore an important modulator of pain experience (Hauck et al., 2015). Pain can be an essential warning of damage to the organism, it distracts and requires attention (Crombez & Eccleston, 1999). Pain often finds its way into our attention rapidly. Pain can also have a threatening factor. The study by Van Damme et al (2008) investigated whether distraction had less effect when pain is perceived as threatening. A cold-pressor procedure was performed, in one group a manipulation of the cold-pressor was performed using instructions giving it a threatening element. They observed that more catastrophic thoughts and fears were reported in the group where a threat manipulation was performed. The results indicate that fewer participants withdrew from the cold-pressor procedure when distracted. It is possible that distraction has effects on behavioural decisions (escape and avoidance) rather than on the pain experience itself (Van Damme, Crombez, Van Nieuwenborgh-De Wever, et al., 2008).

Norman and Shalice (1986) discussed the attention system, highlighting that it is not entirely susceptible to external stimuli. They proposed that part of the attention system operates automatically and is triggered by the environment in relation to specific goals. Attention plays a crucial role in the perception of pain by ensuring that selected sensory events reach our awareness (Legrain et al., 2009). When pursuing a goal, attention can be interrupted by an imposition of a new superordinate goal, such as the goal of protecting the organism from dangerous harm Pain interrupts the ongoing behaviour and imposes the superordinate goal of self-protection (Crombez & Eccleston, 1999).

As can be seen in the previous paragraph, attention is one of the functions in the brain that is directed towards achieving a goal. A distinction can be made between types of goals, namely non-pain related goals and pain related goals. Examples of non-pain-related goals are going out with friends, participating in sports, and more. The allocation of attention resources to complete goal-directed actions has been a topic of concern for researchers (Juravle et al., 2011). Attentional load and attentional set are processes involved in the realization of goals. The attentional load regulates the amount of attention a certain task requires (i.e. when an attentional load is high, there is less attention for other less important goals). The attentional set, this is about the mental set of stimulus features that participant use to identify task-relevant features (Legrain et al., 2009). Even when a stimulus possesses relevant features, even though it is not task relevant, attention will be directed to the features. The attentional set plays a crucial role in the alarm system, as pain immediately demands all attention and interrupts other actions, prompting rapid self-protective responses. (Legrain et al., 2009). Previous studies have employed the primary task paradigm to demonstrate the immediate capture of attention by pain (Crombez & Eccleston, 1999). In this paradigm, participants were instructed to perform a congruent task while experiencing non-task relevant pain. The performance level to the task served as an index (good or bad), indicating that more attention was allocated to pain and less to the task (Crombez & Eccleston, 1999). Numerous behavioral studies have shown that pain reduces when attention is diverted from the stimuli (Van Damme, Crombez, Van Nieuwenborgh-De Wever, et al., 2008).

Goals have an influence on behavior and well-being, although the underlying processes are often not fully understood. A possible reason for this lack of this lack of clarity is that most goal theories focus on individual goals, while in reality, multiple goals can be active alongside each other at the same time. Different goals cannot always be carried out simultaneously, as one may need more attention and thus prevent the other goal from being achieved (Riediger & Freund, 2004). It is also possible when someone focuses their full attention on a single goal, achieving other goals is no longer possible or will be more difficult (Shah, 2005). Attention often prioritizes important goals, and when access to attention for alternative goals is reduced through executive control, it is referred to as goal shielding (Goschke & Dreisbach, 2008; Shah et al., 2002). Research has shown evidence for goal shielding, expecially when individuals are highly driven and committed to an activated goal perceived as important. Additionally, the inhibition of alternative goals seems to be influenced by one’s emotional state, with depression impairing intergoal inhibition and anxiety potentially enhancing it. (Shah, 2005).

Working towards achieving a goal is closely associated with goal shielding, as explained in the preceding section. When discussing action control, especially in a changed environment, it becomes crucial to shield one’s goal. However, it is equally important to remain aware of the environment for potentially important stimuli that might prompt a goal change (i.e. background monitoring). The balance between goal shielding and background monitoring is modulated by response conflicts (Goschke & Dreisbach, 2008). Additionally, goal conflicts also come into play, which is evident in individuals with chronic pain. In cases of chronic pain, there is often a competition between effort to control or avoid pain and engage in day-to-day activities, as one activity tends to exclude the other (Claes et al., 2018). A goal conflict often precedes a goal interference. In fact, goal conflicts arise from incompatible end strategies or limited resources and are often characterized by behavioral indecision (Lewin, 1935; Miller, 1944; Riediger & Freund, 2004). Claes et al (2018) discovered that chronic pain patients did not experience more goal conflicts overall but did encounter more pain-related goal conflicts compared to the control group. These goal conflicts ultimately bring us back to the fear avoidance model (Vlaeyen & Linton, 2012), particularly the motivational component within it. Individuals want to avoid pain, but they also want to engage in enjoyable activities such as socializing with friends (Crombez et al., 2012; Vlaeyen et al., 2009). The pattern of avoidance may correspond to prioritization of pain management goals at the expense of other goals (Claes et al., 2018).

Pain often enters our attention through a bottom-up process, capable of diverting our focus even when engaged in other activities. Although not immediately apparent there can also be top-down control over attention capture in the context of pain (Van Ryckeghem et al., 2013). Van Ryckeghem et al. investigated the extent to which attentional control over pain relies on the attentional set. Most studies adhere to a limited capacity/recourses model of attention and pain, which posits that pain is reduced pain when a cognitive task requires greater capacity or resources. The findings of Van Ryckeghem et al.'s research suggest that the interaction between attention and pain is not fully understood by simple resource/capacity models that solely focus on task difficulty effort. Specifically, the findings indicate that the experience of pain depends not only on the availability of cognitive resources but also on an individual's attentional approach while pursuing goals. The less perceptual features of a task are related to nociceptive stimulus, the less likely pain will capture attention during task performance (Van Ryckeghem et al., 2013). It is important to note that the attentional set is just one top-down variable that may have an effect on pain. Legrain et al. propose that the bottom-up capture of pain by attention is influenced not only by attentional set but executive functioning and the amount of attention devoted to achieving a goal (Legrain et al., 2011).

Based on the aforementioned studies, it can be concluded that a substantial amount of knowledge already exists regarding attentional processes and pain in cognitive tasks. However, there has been considerably less research conducted on how attention to pain stimuli plays a role in the context of motor tasks. Drawing from the fear avoidance model, there can be observed that avoiding painful movements contributes to hypervigilance towards painful stimuli, thereby creating a vicious cycle of increased attention to pain stimuli and further avoidance. Many uncertainties still remain regarding the precise mechanisms through which motor processes impact attention and the associated perception and processing of pain.

The aim of the study conducted by Vanden Bulcke, Van Damme, Durnez & Crombez (2013) is to investigate whether individuals become more sensitive to harmless somatosensory signals in body areas where they expect pain. The results shows that participants who anticipated pain at a specific body part is quicker to notice it compared to when pain is expected. This suggests that their tactile attenuation is directed in advance to the area of the body where pain is expected. Thus, the results indicate that the tactile attention was directed in advance to the area of the body where pain is expected (Vanden Bulcke et al., 2013). Tactile attenuation, also known as tactile suppression, occurs just before and during movement (Juravle et al., 2011). It is typically attributed to a combination of the motor command and the sensory cues resulting from self-generated movement. Specifically, tactile attenuation is attributed to motor command (i.e., the efference copy) (Juravle et al., 2011).

From these findings, it can be concluded that a considerable amount is known about pain and attentional processes and their interactions. Motor command and tactile suppression are discussed in relation to sensory attenuation. This raises the question of whether there is a connection between pain and movement, and how movement affects pain perception. This leads to the concept of sensory attenuation, which is a key phenomenon in this thesis.

Sensory attenuation is a robust and widespread phenomenon of motor control, occurring for somatosensory, visual and auditory stimuli. It serves to prevent an overload of incoming information during movement (Voss et al., 2008). According to Chapman et al. (1987), sensory perception reduces during movement, a phenomenon referred to as sensory attenuation. This reduction in sensory registration is observed for both passive an active movement, with a slightly larger reduction for active movements (Chapman et al., 1987).

There are several possible explanations for sensory attenuation, with the first two being the efferent and afferent explanations. The efferent explanation suggests that the motor system regulates the activity produced by incoming sensory signals (Voss et al., 2008). Studies have initially assumed that the efference copy of the motor command switches off the afferent feedback off the executed action. An efference copy of the motor command is used to generate continuous predictions of the sensory outcomes of the ongoing motor action. The predictions are then compared with the real sensory feedback (re-afference) of the movement. Self-produced sensations can be correctly predicted from motor commands. As a result, little discrepancy will be present between prediction of movement and actual movement. This prediction can be used for sensory attenuation. This is a great contrast to external stimuli because these are not associated with efference copy and cannot be accurately predicted (Blakemore et al., 2000). The study of Voss et al. (2006) suggests that sensory attenuation arises from stages in the motor processing hierarchy, leading to the dispatch of motor commands from the cortex. Additionally, it is hypothesized that sensory attenuation not only occurs during movement execution but also during the preparation phase (Voss et al., 2008). De Voss et al. (2008) conducted two experiments. His second experiment aimed to test the hypothesis of whether sensory attenuation occurs not only during movement execution but also during movement preparation. In experiment 2, we saw attenuation of a probe to the right finger even when the left finger was pointed and then moved, while the right finger did not move. This attenuation cannot be attributed to retrospective afferent masking or motor commands, as the right finger did not move. Instead, it is suggested that in experiment two, the participants expected a cue on the right side and therefore prepared for a movement of the right finger. This was confirmed by their shorter time for a reaction. The study demonstrates that this preparation alone is sufficient to cause sensory attenuation, indicating that action preparation has a significant impact on somatosensory perception, even when the motor command is not actually executed (Voss et al., 2008). The preparation process involves various process, including anticipatory selection of appropriate motor responses (de Jong et al., 2006), and appropriate shifts of attention (Posner et al., 1980). The direction of sensory modulations in the study supports the notion that the results reflect motor preparation rather than attenuating it (Voss et al., 2008).

On the other hand, the afferent explanation suggests that the reafference sensations of the moving body can potentially disable the sensation stream.

Sensory attenuation occurs with both passive and active movements, where it was first assumed to only occur during active movements (Chapman et al., 1987). This was also demonstrated by Chapman et al. (1987) with his animal and human experiments. The reduction in sensory information transmission to the thalamus and sensory cortex observed for both passive and active movements, with a slightly stronger reduction for active movements (Chapman et al., 1987). However, cortical changes are not observed during passive movements, indicating that the mechanism starts after the movement (Voss et al., 2008).

In the research of Haggard & Whitford (2004) it is suggested that motor prediction may also explain the phenomenon of sensory attenuation during voluntary movement. Motor predictions represent predictions of systems which are directly and most of the time immediately affected by our motor commands. Thus, voluntary actions cause suppression of neural activities in the sensory area and inhibits levels of conscious sensations (Haggard & Whitford, 2004). These predictions can anticipate how our body moves in response to motor commands, similar to how a car responds to our foot movement on the pedals (Wolpert & Flanagan, 2001).

Furthermore, there are some other key concepts that are important to understand sensory attenuation properly. For instance, forward models, which are internal representations within the central nervous system. These models provide an internal representation of the body and environmental signals (i.e. an internal forward model) used to predict the consequences of outgoing motor commands. They help attenuate unnecessary information and enhance essential sensory information for movement control. For example, when an individual tickles themselves, the perception is less ticklish compared to when it is done by a third party (Juravle et al., 2011).

Although sensory attenuation serves the purpose of efficient movement execution (Bays & Wolpert, 2007; Gallace, et al., 2010), it is not absolute. Movement can still be interrupted by more important demands or goals, such as pain (Van Hulle et al., 2013). For instance, in the research of Van Hulle, et al., (2013), they studied a group of low back pain patients. It was found that there are overly attentive to pain sensations in their back. This over-attentiveness was not found for people without back problems. The attenuation of tactile stimuli during movement is also reduced when participant’s attention is manipulated toward the location of the stimuli (Van Hulle et al., 2013).

Current studies have confirmed that pain experience reduces during movement (Babiloni et al., 2005; Le Pera et al., 2007). However, studies that discuss pain and sensory attenuation do not specifically address pain with a threatening factor. The presence of threatening factor can significantly influence pain perception, as pain becomes more demanding when perceived as highly threatening (Crombez & Eccleston, 1999). For example, cancer pain is rated as more severe than labor pain because cancer is perceived as more threatening than childbirth (Gatchel et al., 2007). Threat appraisal refers to the perception of physical sensations as harmful, leading individuals to search their body for threatening sensations (Crombez et al., 2005). This is an example of hypervigilance discussed in detail earlier at the fear avoidance model.

Patients with chronic pain often report that their pain experience is influenced not only by their own sensations but, also by external information from sources such as doctors, friends, or the internet. This information can either amplify or alleviate the perceived threat value of pain. For instance, consulting information on the internet may increase concerns about pain (i.e. amplification) while finding reassurance about still being able to move despite pain can provide relief (i.e. alleviation) (den Hollander et al., 2015).

Creating a threat in an experimentally controlled setting is challenging, because participants may not fully believe the manipulation being applied by the researcher. Additionally, ethical considerations and the participants’ ability to stop the experiment at any given moment can limit the effect of fear conditioning studies on humans (den Hollander et al., 2015).

While extensive research has been conducted on pain and the influence of cognitive and motor processes, further investigation is still needed to understand how pain and sensory attenuation occur together. It is also noteworthy that very little research has been conducted in how the treat of a painful experience and sensory attenuation influence each other.

The way pain effects the motor system is known, but the way the motor system influences pain has not yet been extensively researched. Therefore, the choice was made to conduct an investigation in this area. The objectivity of this research is to investigate to what extent sensory attenuation occurs in the domain of pain and whether movement has an influence on this. Two research questions were formulated to research this objective:

1. Does sensory attenuation occur during pain, and does it occur during movement preparation and/or movement execution?
2. Does threat have an effect on sensory attenuation?

Regarding the first research question, the hypothesis is that sensory attenuation will occur during pain and that the suppression occurs in the movement preparation and movement execution condition. The hypothesis for the second research question is that threat does have an effect on sensory attenuation. The rationale is that when pain occurs in a high treat environment, more attention is devoted to it which then heightens the pain experience.

Methodology

Participants and design

The study was conducted at the Faculty of Psychology and Educational Sciences of Ghent University. The experimental set-up consisted of a table with a research computer.
There were 91 participants in this study, 12 participants were excluded. The criteria for exclusion were based on an outlier analysis that was conducted in R. Participants for whom the PSE was higher than the upper and lower boxplot cut-off limits were excluded from the analysis. The formula used to calculate the lower limit was: (Q1 [first quartile] −1.5 × IQR [inter quartile range = Q3—Q1]). The formula used for the upper limit calculation was: (Q3 [third percentile] + 1.5 × IQR). Participants who scored high on this formula gave consistently the same response at the task (ie. “left/right hand stronger”). This resulted in the estimation of the PSE being extremely high or low. In the end there were 79 participants were included (age 18 – 75). The sample size was based upon a power analysis (80% power with a medium effect size). Only right-handed participants were included in the study, to reduce possible sensory differences between both hands, and to avoid the risk of pain habituation after going through several trails.

Participants were recruited via a recruitment platform for voluntary participation in experiments (Sona platform http://ugent.sona-systems.com). This platform is available within the network of Ghent University. Both students from Ghent University and individuals from the general population can be recruited. When the inclusion criteria (age 18 – 75, right-handed people, people without current or a history of psychiatric disease or movement disease, no chronic pain patient, people without electronic devices implantations or people who aren’t pregnant) were met, participants were allowed access to the calendar to register. To facilitate the recruitment of the desired sample size, participants received a cash refund of 15 euro or 1 credit at the end of the experiment. For this experiment a mixed experimental design was used. The study consisted of one within subjects’ factor (movement: rest, preparation, and execution) and one between factor (group: high vs low threat).

Materials and Methods

Initial room set-up

The experiment was collected in a research room, the room contained a desk with laptop, monitor, two digitimer, a sensor box and three chairs. Four lubricated Medcat Ag/CIAg surface electrodes (1cm diameter; Antwerp, Belgium). The administration of the electrical stimuli went through a Constant Current Stimulator (DS5; digitimer Ltc, Hertfordskire, United Kingdom). The electrodes were used to administer the painful stimuli. The electrodes were attached to the skin of the participants, the exact area of application was next to the ulnar styloid bone of both hands. For the attachment double sided taper rings were used. Before the sensory attenuation task could take place, the tolerance procedure had to be completed.

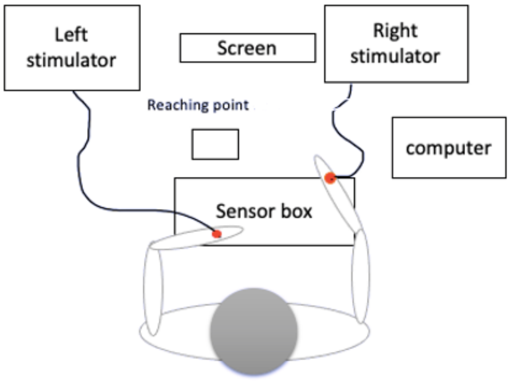


Figure 4. A schematic representation of the experimental set up.

Measurement tolerance

First, the tolerance level of each individual participant was established by following a staircase method. Participants first received a shock of 0.5 mA, after which the intensity was increased with 1 mA up until the participant indicated to stop. Tolerance was explained and defined as the intensity that was as painful as possible but that the participant was still willing to tolerate. The participants were ensured that no higher stimulus than their tolerance level would be administered during the experiment.

Calibration

When the tolerance level was obtained, 20 random stimuli were selected between 0.25 mA and the tolerance level. After the stimuli, participants were asked to indicate the intensity of the perceived pain on a scale from 0 to 100, where 0 was considered as not painful and 100 was considered very painful. Based on these ratings, a 1-10 scale of intensities was estimated per participant. The mA corresponding to each subjective pain intensity was estimated using a linear trend line. The script for the calibration procedure was developed in Inquisit software (Version 5). This intensity scale was used in the Sensory Attenuation Task. Subsequently, the intensities used in the sensory attenuation task were selected. The following range of intensities was used: 2, 3.5, 5, 6.5 and 8.

Hand match procedure

After obtaining the intensity scale for each participant, a matching procedure was performed on the left and right hand to ensure comparable intensities on both hands. The intensities at the left hand were modified (increasing of .5 mA and decreasing of .1 mA) until the left hand stimuli and the right hand stimuli were perceived equal. Subsequently, the intensities used during the experiment were selected.

Sensory attenuation task

In this task, participants were asked to perform movements to reach an indicated point on the desk in front of them. An initial cue was given indicating whether to prepare movement (bar with plus sign) or to not prepare movement and thus stay in rest position (bar with negative sign). The bar disappeared after 5 seconds, after that participant had to perform the movement. Participants were also informed that reaction times were measured to keep them focused. This also ensured the researchers that the participants were preparing the movement. Two electrical pain stimuli (ES bipolar, 50 Hz, 500 ms) were administered simultaneously at fixed intervals during either the motor preparation phase, the motor execution phase or the rest phase (no movement prepared) using Constant current Stimulator (DS5; digitimer Ltc, Hertfordskire, United Kingdom) and two speared Medcat surface electrodes (1cm diameter, Antwerp, Belgium). In two of the phases, motor preparation and rest phase, the pain stimuli were given at the moment the bar disappeared. In the motor movement phase, a motion monitoring system was used. This sensor box had an optical sensor that detected when motion was initiated. Upon movement of the participant, the stimuli were administered. When the participant moved too fast, the message "too fast" appeared on the screen and the trial had to be restarted. The next trail was only started when the hand was correctly positioned near the sensor, to ensure that both hands were in starting position and that the pain is only administered during movement execution. On the left hand (reference hand), the intensity of the pain stimulation was kept constant, while the intensity was changed randomly above or below that constant intensity on the right hand (test hand).

After each trial, the participant was asked to report in which hand they experienced the highest the stimulus using a two-alternative forced-choice (2AFC) paradigm. This paradigm has been implemented before in testing sensory attenuation (Voss et al., 2006). For analytical purposes, the responses were adjusted with a logistic function according to a maximum likelihood procedure. This allowed the calculation of the "point of subjective equity" (PSE), which corresponds to the virtual intensity at which the pain applied in the reference hand is perceived equal to the test hand. A total of 150 trails were administered in this study. There are 50 trials per condition. 50 rest trials: In this trial, the painful stimuli were administered simultaneously with the disappearance of the bar. 50 movement preparation trials, in which the stimuli are presented just before the actual movement initiation (i.e. when the bar disappears). 50 movement trials, in which the stimuli are presented during movement execution (when the movement initiation is detected by the optical sensor).

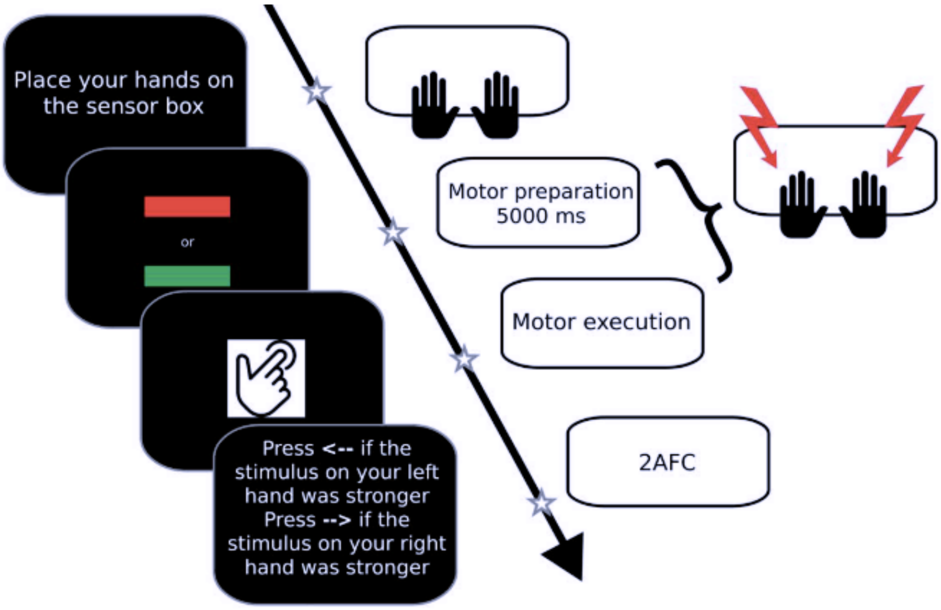


Figure 5. A visual representation of the Sensory attenuation task. (E. A. Pinto et al., 2021)

Threat manipulation

The threat manipulation task consisted of different instructions given at the beginning of the experiments. Participants were divided into two groups (a threat group and a neutral group), and randomly assigned to one of the two groups. The difference in these groups consist in their instructions. In the threat group the instructions given where more focused on the threat, the stimuli were presented as potentially harmful whereas in the neutral group the stimuli were presented as neutral. In both groups, it was first pointed out that the experiment would be conducted with electrical stimuli applied through electrodes, two electrodes were attached to their non-moving hand therefore they were able to monitor their skin sensitivity on a visual scale on a computer screen. This visual scale (figure 4) contained three zones: a green zone for low sensitivity, an orange zone for medium sensitivity and a red zone for high sensitivity. The electrode attached to the non-moving hand is a fake electrode and gives a false image on the dynamic pointer, it is a pre-programmed image used in the trials. The participants have not been informed of the electrode's falsity.

The explanation in the threat group focuses on high sensitivity and some possible consequences such as redness of the skin, and exceptionally also burning sensations and blisters around the electrodes. Participants were told that the skin could become more sensitive by receiving several stimuli. In the neutral group, participants were told that their skin sensitivity will lessen, habituate. The complete instructions are described in Appendix 1.

Figure 6. An example of the pictures that represented the sensitivity of the skin, i.e. the threat group on the left and the neutral group on the right (E. Pinto, 2019)

During the measurement, the dynamic pointer only moved in the green zone in the neutral group, while it only moved in the orange zone in the threat group. The pointer never moved in the red zone.

Fifty different animated pictures were shown during each of the 150 trials. The animated pictures were shown together with the motor cue (+ or – bars). The trials were subdivided into 50 counterbalanced blocks. After each block, 7 questions were presented to check the effectiveness of the manipulation, the questions are described in Appendix 2.

Debriefing

After completion of the experiment, participants got a debriefing explaining the objective of the study. The following debriefing was given: “In the first part of the experiment, you were either asked to move or to stay in rest position. We then applied painful stimuli during either rest, motor preparation or motor execution and asked you to identify the hand in which you felt the stimulus more strongly. This allows us to calculate to what extent your somatosensory processing of pain was affected by preparing or performing a movement. This phenomenon is defined as sensory attenuation. Furthermore, we wanted to examine whether this effect was reduced when individuals were stimulated to pay attention to pain by manipulating its potential threatening value. Therefore, participants were randomly assigned to two different experimental groups. One group was given neutral instructions about the procedure and about their skin sensitivity. The other group was told that their skin reacted more strongly to the electrocutaneous stimuli and that this could mean a more uncomfortable experience. You were part of the (...) group. However, we did not really record your skin sensitiveness and the indicator we displayed on the screen was "fake" and preset to move. The electrodes were indeed attached, and the images of the indicators were only used to make the experimental procedure more believable.

Data analysis

The statistical analysis was performed using JAPS Computer Software (202 Version 0.13.1). The significant evidence level is at $p< .05$.

To investigate the significance of the first hypotheses which states that sensory attenuation will be generalizable to pain and that the suppression will occur in the movement preparation and movement execution condition and won't occur in the rest condition. The test used was the PSE which was possible through the 2AFC paradigm. The PSE corresponds to the virtual intensity at which the pain applied in the reference hand is perceived equal to the test hand, i.e. the PSE is found at the intensity corresponding to the 50% probability that the pain on the right hand is experienced as equally painful as on the left hand. the assumption made in PSE is that the participants do not know which stimulus is stronger (no difference) so they will gamble which stimulus is stronger. The presumption behind this is that when participants don't know which stimulus is stronger (when they feel no difference between the two stimuli), they tend to guess (i.e. with a 50% probability for each choice). The PSE was estimated for three different conditions. After the PSE estimation, the sensory attenuation index gets calculated it was estimated per participant, per condition (rest, movement preparation and movement execution condition). The sensory attenuation index was identified and calculated as an increase above the rest level in the motor preparation and execution phases.

Two different formulas are used to obtain the percentages of the sensory attenuation: (PSE execution – PSE rest)/PSE rest. For the preparation condition: (PSE preparation – PSE rest)/PSE rest. A mean PSE was calculated for each within-subject experimental condition (rest, motor performance, and motor preparation) in both experimental groups. A representation of the sensory attenuation index is shown as follows: how larger the administered pain stimuli on the moving hand, during motor preparation and motor execution compared to the rest phases, must be perceived as equally painful as the administered reference stimuli to the nonmoving hand. We had to verify whether the preparation condition and the execution condition were significantly different from the resting condition. The resting condition was the baseline and is equal to zero.

To investigate whether sensory attenuation to pain stimuli occurred, we examined whether the SAIs (sensory attenuation indexes) differed from 0 during motor preparation and execution separately for the threat and neutral group, using the 1-sample t-test (test value 0). We expected an effect in both, movement preparation condition and movement execution condition.

To examine whether there is more attention devoted when there is a threat and that as a result less sensory attenuation occurs. We used a 2 (motor preparation condition vs motor execution condition) X 2 (neutral vs threat group) RM ANOVA to test whether the sensory attenuation indexes were significantly different during motor execution and motor preparation and between the neutral and the threat group.

Results

Descriptive statistics

The total number of participants is 91. However, twelve participants are excluded, and the data analysis is thus performed on 79 participants, of which 61 female and 18 male. The participants are between the age of 18 and 52, with a mean age of 23.3. The participants are divided into two groups, a neutral group with 38 participants and a threat group with 41 participants. The neutral group consist of 8 men and 30 women, with a mean age of 24.5 (SD = 6.579; minimum age is 18 and maximum age is 52). The threat group is made up of 10 men and 31 women and the mean age is 22.2 (SD = 3.215; minimum age is 18 and maximum is 35). A one sample t-test indicated that the groups are not equally divided in terms of age (t = 2.020, p = 0.047). The groups are however equally divided in terms of gender ($\chi^2 = 0.125$, p = 0.724).

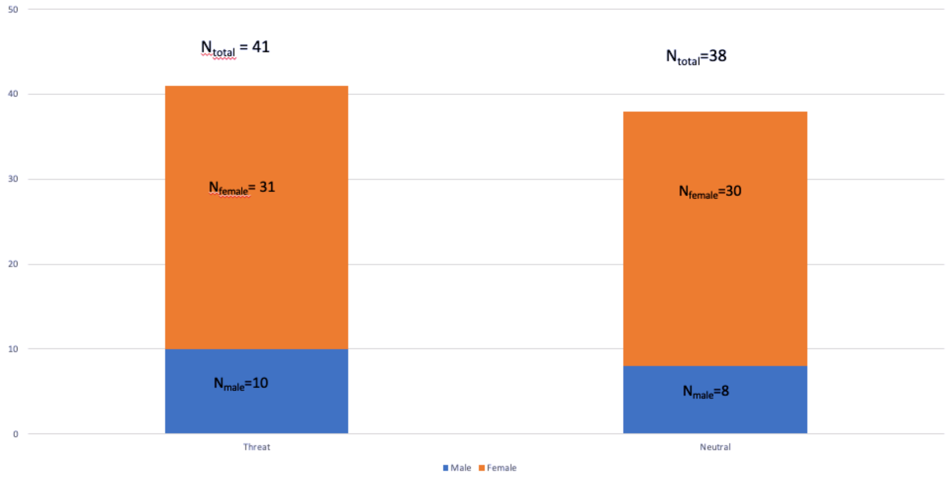
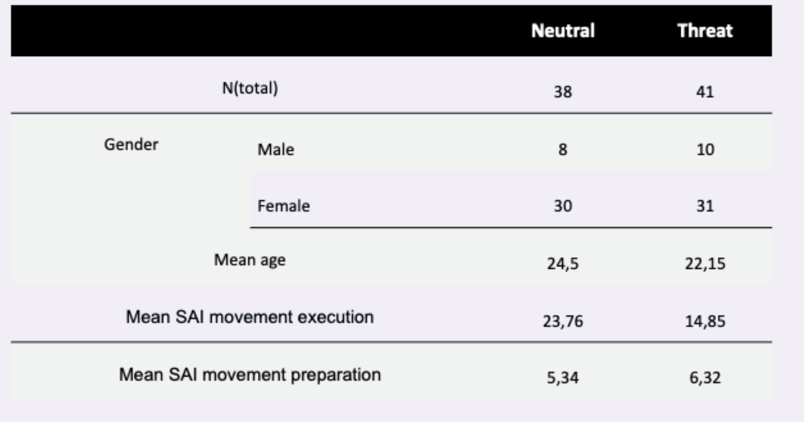


Figure 7. Graphic representation on the gender of the participants.

Hypothesis testing

The first research question of this study is to investigate if sensory attenuation occurs during pain, and whether it occurs in the movement preparation and/or movement execution phase in both the neutral and threat group. We hypothesize that sensory attenuation will occur during pain and that the attenuation occurs in the movement preparation and movement execution condition in both groups, i.e. that the SAI will be greater than 0. Our analyses suggest that attenuation occurs for the neutral group during movement execution (mean = 23.757%, SD = 29.273, $W_{(37)} = 677.000$, $p < 0.001$, $r_{rb} = 0.827$), but not for the movement preparation condition (mean = 5.337%, SD = 27.407, $W_{(37)} = 469.000$, $p = 0.157$, $r_{rb} = 0.266$). Similar results are obtained for the threat group, where the SAI was greater than 0 during movement execution (mean = 14.846%, SD = 40.212, $W_{(40)} = 653.000$, $p = 0.003$, $r_{rb} = 0.517$) while this was not found during movement preparation (mean = 6.320%, SD = 45.913, $W_{(40)} = 502.000$, $p = 0.361$, $r_{rb} = 0.166$). The higher SAI values in the movement execution phase for both groups is also confirmed by the repeated measures ANOVA results, which indicate a significant effect for the movement phase, with the SAI being higher during movement execution than during the movement preparation ($F_{(1,78)} = 20.340$, $p < 0.001$, $\eta_2^p = 0.207$). These results imply that sensory attenuation only occurs during movement execution, and thus not during movement preparation.



		Neutral	Threat
N(total)		38	41
Gender	Male	8	10
	Female	30	31
Mean age		24,5	22,15
Mean SAI movement execution		23,76	14,85
Mean SAI movement preparation		5,34	6,32

Figure 8. A chart with several variables. These include the total number of participants of the two groups (neutral and threat). A distinction was made between men and women. Furthermore, the mean age of participants in both groups is displayed. Finally, the mean of the SAI (sensory attenuation indexes) belonging to movement execution and to movement preparation of both groups are shown.

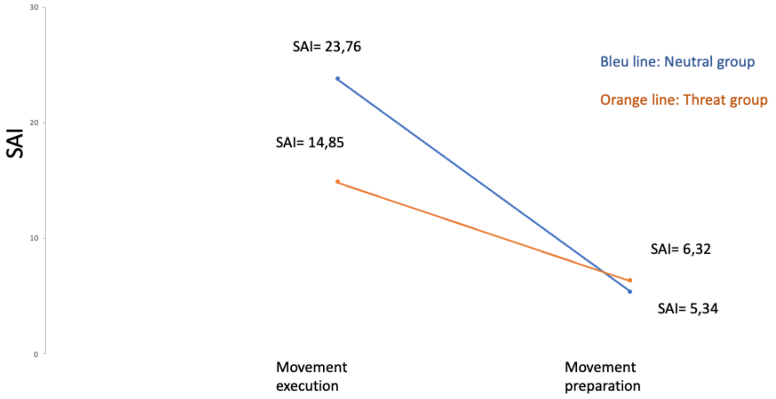


Figure 9. A line chart where the SAI's of the neutral group (blue) and the threat group (orange) are shown for the movement execution and the movement preparation. It illustrates that the SAI's of the movement execution are significantly higher than the SAI's of the movement preparation.

The second research question concerns the effect of threat on sensory attenuation, for which we hypothesize that it does have an effect. When pain occurs in a high treat environment, more attention would be devoted to it, reinforcing the pain experience. The repeated measures ANOVA indicates no significant effect for the group (threat vs. neutral; $F_{(1,78)} = 0.134$, $p = 0.715$, $\eta_2^p = 0.002$) or for the movement x group interaction ($F_{(1,78)} = 1.841$, $p = 0.179$, $\eta_2^p = 0.023$). This implies no effect of threat on sensory attenuation.

A manipulation check is also done to check whether the threat manipulation was successful. A successful manipulation would result in higher scores on the 7 items of manipulation in the threat group compared to the neutral group. The one-tailed nonparametric Mann-Whitney U test is used as the scores of all items but 'meter monitoring' have a non-normal distribution. The score for 'fear of increase in sensitivity' is significantly higher ($p < 0.001$) in the threat group (3.321 ± 2.068; mean ± standard deviation) compared to the neutral group (1.886 ± 1.648). This result is also found for 'meter monitoring' (threat group: 4.980 ± 2.423, neutral group :3.816 ± 1.895, $p = 0.013$), 'expectancy of increase in sensitivity' (threat group: 5.679 ± 2.387, neutral group: 3.728 ± 2.166, $p < 0.001$) and 'attention to negative effects' (threat group: 4.248 ± 2.716, neutral group: 3.254 ± 2.518, $p = 0.048$). No significant difference ($p > 0.05$) was found for 'certainty the 2AFC task', 'fear of stimuli', and 'distraction'. The manipulation checks thus yielded mixed results, which might influence the obtained results.

Discussion

The objective of this research was to investigate to what extent sensory attenuation occurs in the domain of pain and whether movement has an influence on this. The two related research questions were the following:

1. Does sensory attenuation occur during pain, and does it occur in the rest, movement preparation and/or movement execution condition?
2. Does threat have an effect on sensory attenuation?

It was hypothesized that sensory attenuation would occur during painful experiences, and it was further postulated that this suppression would take place during both the movement preparation and movement execution conditions. The results of the study provided compelling evidence supporting the presence of sensory attenuation by pain during the movement execution. This phenomenon of sensory attenuation during motion has been consistently observed in various studies, including previous research. Notably, sensory attenuation has been observed in both passive and active movements, although its occurrence tends to be slightly more prominent in active movements (Chapman et al., 1987). For instance, a study conducted by Haggard and Whitford (2004) concluded that voluntary actions elicit a reduction in neural activity within sensory regions of the brain, resulting in a decrease in conscious sensations (Haggard & Whitford, 2004).

However, it can be concluded that for the movement preparation condition there is no significant presence of sensory attenuation during pain. These results are not in line with previous research. In the study conducted by Voss et al. (2008), two experiments were carried out, and the findings of the second experiment indicated the presence of sensory attenuation during movement preparation (Voss et al., 2008). it is assumed that there are several possible explanations for sensory attenuation. Two potential processes that have been proposed are the efferent and afferent explanation. Initially, it was believed that the efferent copy of motor command inhibits the afferent feedback for the executed action. However, it was observed that when the output of the motor command from the primary motor cortex is artificially delayed, sensory attenuation occurs at the intended movement as opposed to the delayed movement (Voss et al., 2006).

A possible explanation for the lack of significance in sensory attenuation during the movement preparation could be related to the availability of attentional resources in the brain. Attention to other tasks may be less pronounced, but since pain can be perceived as a threat to life, it may still receive prioritization. Allocating attention requires substantial resources and because less attentional space is occupied during movement preparation, it may be absorbed more quickly compared to during actual movement. Indeed, upon examining the results, it can be observed that SAIs for movement execution were considerably higher that SAIs for movement preparation, which could support this speculation.

Another potential explanation for the observed sensory attenuation during pain perception is the anticipation and prediction of pain. When individuals are aware that pain is imminent, their brain may generate predictions about the upcoming pain, leading to a reduction in perceived pain intensity. A study conducted by Blakemore et al. (2000) might support this idea by discussing the concept of an efference copy of the motor command. This efference copy continuously generates predictions of ongoing actions, which are then compared with the actual sensory feedback (re-afference) received during the execution of the movement. When individuals perform voluntary movements themselves, the predictions closely match the actual execution, leading to minimal discrepancy (Blakemore et al., 2000). In such cases, the predictions can contribute to sensory attenuation, reducing the perceived intensity of sensations, this may also be the case for pain.

Furthermore, we hypothesized that threat would have an impact on sensory attenuation, as increased attention to pain in a high-threat environment could intensify the pain experience. However, the results revealed that this hypothesis was incorrect, as no effect of threat on sensory attenuation was observed. These findings contradict previous research. Crombez & Eccleston (1999) concluded that the mere anticipation of pain can enhance the perception of pain stimuli. Additionally, studies have shown that directing attention to pain, increases pain perception compared to when attention is focused elsewhere (Van Damme et al., 2010). Conversely, when attention is diverted away from pain, it can lead to a reduction in pain experience (Van Damme et al., 2010).

However, it was also expected, based on the fear-avoidance model, that there would be consequences associated with the threat component of pain (Quartana et al., 2009). It is anticipated that when individuals perceive pain as threatening, such as when they misinterpret pain as a signal of a severe injury or an uncontrollable disease, it triggers a heightened fear of pain or injury. The fear-avoidance model incorporates concepts like catastrophizing and hypervigilance. Catastrophizing, in particular, can be understood as a collection of exaggerated and negative cognitive and emotional patterns that manifest in response to actual or anticipated pain stimuli. Furthermore, catastrophizing involves a tendency to amplify the threat value of pain stimuli, experience feelings of helplessness in relation to pain, and exhibit a relative inability to suppress pain-related thoughts leading up to, during, or after a painful event (Quartana et al., 2009). This catastrophic thinking instills a fear of movement, resulting in the avoidance of physical activities due to the belief that they may exacerbate the pain. This avoidance behavior can have negative consequences, such as a slower healing process for strains (Crombez et al., 2012).

Additionally, hypervigilance, characterized by the automatic selection of pain or pain-related information while suppressing other environmental cues, plays a significant role in pain perception. Pain becomes the primary focus and can be distressing for the individual experiencing it. Hypervigilance is driven by the fear system (Crombez et al., 2005). Two key considerations are crucial in understanding hypervigilance towards pain: (i) hypervigilance emerges when an individual's goal is related to pain avoidance and escape, and (ii) hypervigilance is primarily believed to be an automatic process (Crombez et al., 2005). In the short term, hypervigilance and avoidance may not appear to have any negative consequences, as they can be seen as protective mechanisms that prevent further injury and allow time for healing. However, when examining the long-term effects, these behaviors are considered dysfunctional and can lead to increased pain and suffering. Moreover, the impact of this suffering is not limited to physical aspects alone; it can also have profound effects on one's mental well-being. The consequences may include a depressive mood and physical deconditioning (Crombez et al., 2012).

Hypervigilance is a phenomenon rooted in attention. Individuals experiencing pain often struggle with shifting their attention away from pain or pain signals, as it remains their primary focus (Crombez et al., 2005). Attentional selection does not occur uniformly for all stimuli.

Notably, fear-relevant stimuli are known to be detected more quickly than fear-irrelevant stimuli (Ohman et al., 2001). This observation was demonstrated in a study conducted by Ohman et al. (2001), where fear-irrelevant stimuli (e.g., flowers and mushrooms) and fear-relevant stimuli (e.g., snakes and spiders) were utilized to examine which images attracted attention most rapidly. Participants noticed the images with snakes or spiders more quickly than those with flowers and mushrooms. This finding indicates that fear exerts an influence on attentional selection. All of this indicates that there was a different expectation, and the mixed results were rather a suprising outcome.

The mixed results obtained from the manipulation check may explain the absence of an effect regarding the threat variable. There are two potential explanations for these conflicting findings. Firstly, administering a highly threatening pain stimulus presents difficulties in an experimental setting due to participants' expectation of safety, as they have been provided with an informed consent prior to the study, explicitly stating that the experiment would be conducted in a safe manner. Experimental pain is always carefully controlled and can be terminated at any given moment (den Hollander et al., 2015). Secondly, a significant proportion of the participants were students who are typically familiar with experimental setups and may not have perceived the threat as genuinely threatening.

Methodological factors may also contribute to the mixed results observed. The outcomes of the manipulation check were somewhat ambiguous, which could have hindered the detection of effects in the study. It is possible that the questions posed during the manipulation check were unclear for the participants, leading to an incomplete or inaccurate assessment of the intended manipulation. To ensure accurate measurement and interpretation of the manipulated factors, it is crucial to refine and clarify the wording of the questions or instructions provided during the manipulation phase. By doing so the validity and reliability of the obtained results can be enhanced, allowing for a more precise analysis of the intended effects.

Another variable that may influence the results is the participants composition. Notably, a substantial number of participants were female. The overall average of age was 23,3. This demographic skew may introduce bias in the results, as it has been suggested that women may report pain more readily than men (Drieskens et al., 2018).

Research plays a crucial role in obtaining a clearer understanding of how pain affects individuals and how factors such as attention and threat contribute to this process. It is noteworthy that pain symptoms are experienced by approximately 30% of the global population (Drieskens et al., 2018). The biopsychosocial model further emphasizes that the impact of pain extends beyond individual physical discomfort. Indeed, these complaints can have implications for mental well-being, and the social environment also plays a significant role in this context. Individuals may encounter challenges related to acceptance or develop mental health issues due to the complexities surrounding pain (Gatchel, 2004).

For future research, it would be valuable to replicate the study with a more heterogeneous participant group. Additionally, exploring intermittent movements without a constant pain stimulus could provide interesting insights into how individuals react when pain stimuli are not consistently anticipated. Moreover, investigating the responds of individuals when multiple stimuli simultaneously administered, such as auditive stimuli during movement. This way, there is another study that examines the same subject, and it can be checked whether the results when a different sense is used are the same. A threat manipulation could also be applied in this context, for example by indicating that when a high-pitched tone will be accompanied by a more painful stimulus.

Another potentially interesting idea for research may be to explore the intricate mechanisms underlying the relationship between anticipation, prediction, and sensory attenuation in the context of pain. Investigating how cognitive factors, such as expectations and conscious awareness, interact with neural processes will provide valuable insights into the modulation of pain perception. Because the phenomenon of increased sensory attenuation through conscious anticipation may have the potential to influence pain perception and might be a factor in pain modulation. When individuals expect pain, their cognitive and neural processes may actively dampen the pain signals, leading to a reduced subjective experience of pain.

Based on our conducted research, we can conclude that sensory attenuation occurs during movement, indicating a reduction in the processing of pain stimuli while moving, furthermore the manipulation check revealed that threat does not impact the perception of pain.

Appendix

Appendix 1

From the research protocol Pinto (2021), these are the verbal instructions given to the participants.

Neutral instructions experimental group

In this experiment we will use electrocutaneous stimuli to investigate pain processing. Skin sensitivity to these stimuli can vary among people and during the experimental procedure. Since skin sensitivity can affect pain perception, we need to measure it during the experiment. For this reason, we placed these electrodes that will measure your skin sensitivity during the task. You will be able to monitor your skin sensitivity by checking an indicator that will be displayed at the bottom of the computer screen during the task. This indicator can vary on a continuum from a green zone to an orange and a red zone. The zone indicates that your skin reacts perfectly normal. The more the pointer moves to the red side of the bar, the more strongly your skin reacts. When the detected sensitivity is too high (red zone), the experiment will automatically stop. Nevertheless, during the calibration your skin reacted perfectly normal. Usually, the skin habituates to the pain stimuli during the experiment and the sensitivity decreases.

Threatening instructions experimental group

In this experiment we will use electrocutaneous stimuli to investigate pain processing. Skin sensitivity to these stimuli can vary among people and during the experimental procedure. Too high skin sensitivity can affect pain perception and can be associated with reddening of the skin and in rare cases with burning sensation or blisters on the electrode sites and this could make the procedure more uncomfortable. For this reason, we measure it during the experiment with these electrodes. I noticed that during the calibration your skin reacted quite strongly to pain stimuli. You will be able to monitor your skin sensitivity on the bottom of the computer screen during the task. This indicator can vary on a continuum from a green, zone to an orange and a red zone. The more the pointer moves to the red side of the bar, the more strongly your skin reacts. Please take into account that, skin sensitivity can increase during the experiment as an effect of the repetitive administration of stimuli. However, in case of too high sensitivity detected (red zone) the experiment will automatically stop.

Appendix 2

The questions asked to check the effectiveness of the manipulation:

1) "How afraid were you that the indicator would show an increase in your skin sensitivity?
0= not afraid at all; 10= very afraid"

2) "To what extent were you attentive for potential negative effects of the stimuli on your skin?
0= never; 10= always"

3) "To what extent did you monitor the indicator of your skin sensitivity during the trials?
0= not attending at all; 10= very focused on the indicator"

4) "How do you expect your skin sensitivity to increase in the following trials?
0= not al all; 10= very strong"

5) "How sure are you about your answers regarding in which hand the stimulus was stronger?
0= not sure at all; 10= very sure"

6) "How afraid of the stimulus were you?
0= not afraid at all; 10= very afraid"

7) "To what extent did the stimuli divert your attention from the movement task?
0= not distracted at all; 10= very distracted"

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