Physiological Mechanisms Underlying the Passive Defence Response in Human Individuals: A Systematic Review

Karlijn Dragt

Master thesis – Developmental Psychology

S3758192
February 2024
Department of Psychology
University of Groningen
Daily supervisor: dr. L.S. Cuijpers

Abstract

Background: Exposure to a traumatic event is a common human experience, with approximately 65% of the individuals in the Netherlands having undergone such an event. Traumatic events can elicit a range of responses, including what is commonly referred to as the ‘freeze response’. The freeze response is a natural survival mechanism observed in individuals facing threats, yet the physiological mechanisms underlying this response remain poorly investigated among human individuals.

Objective: Within this systematic review, we synthesize research which investigate the physiological mechanism that underlie the human passive defence response (i.e., initial freeze response, tonic- and collapsed immobility).

Method: A systematic search for matching publications was performed using PubMed and Medline. From 971 initially identified studies investigating the physiological mechanisms that underlie the human passive defence response, 10 studies (n = 324) were included in the final analysis.

Results: Among the ten selected studies, heterogeneity was observed in several study characteristics, including participants characteristics and methodological measurements. In examining heart rate responses, a consistent trend was identified among individuals without trauma exposure, where all studies reported a decrease in heart rate responses. In contrast, the individuals with trauma exposure, including those with PTSD, exhibited variability in heart rate responses, with some studies indicating an increase and others a decrease. Similar results were observable for body sway responses. Trends in body sway were apparent among individuals without trauma exposure, exhibiting reduced body sway responses. However, such a trend was not evident among those with trauma exposure, as one study revealed no significant difference, another indicated an increase, and a third reported a decrease. Although skin conductance was evaluated in only one study, the expected outcome of an increase in skin conductance was observed.

Conclusion: The results suggest different patterns in physiological responses between individuals with and without trauma exposure. Specifically, individuals without trauma exposure typically exhibit an expected reduction in heart rate and body sway. On the contrary, these patterns are not consistently observed in individuals who have been exposed to trauma.

Keywords: passive defence response, freeze response, tonic immobility, collapsed immobility, physiological mechanisms, heart rate, body sway, skin conductance

Introduction

Last year, a friend of mine encountered a traumatic nocturnal intrusion when an unfamiliar man abruptly entered her room. This unexpected confrontation left her in a state of shock, causing her to momentarily freeze. Fortunately, the open door allowed her to consider her options. As the intruder communicated with her in an unfamiliar language, my friend began to regain her calmness. Faced with the need for communication, my friend grabbed her laptop, aiding the intruder to use Google Translate to convey his intentions. Just as he was about to begin the translation process, my friend made a rapid escape from her room and ventured outdoors seeking help. Luckily, my friend managed to escape unharmed and the intruder was caught by the authorities. Nevertheless, the incident had lasting consequences, resulting in my friend enduring ongoing trauma in the aftermath.

Unfortunately, exposure to a traumatic event, akin to the aforementioned encounter, is a common experience for humans, with 65.6% of the Dutch population having undergone such a distressing event, as reported in the study conducted by Benjet et al. (2015). The fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) defines a traumatic event as follows:

> Exposure to actual or threatened death, serious injury or sexual violence, in one (or more) of the following ways: 1) Directly experiencing the traumatic event(s), 2) Witnessing, in person, the event(s) as it occurred to others, 3) Learning that the traumatic event(s) occurred to a close family member or close friend. In cases of actual or threatened death of a family member or friend, the event(s) must have been violent or accidental, 4) Experiencing repeated or extreme exposure to aversive details

> of the traumatic event(s) (e.g., first responders collecting human remains; police officers repeatedly exposed to details of abuse). (Mash & Barkley, 2014, p. 480).

Much like my friend, when facing a traumatic event, individuals often exhibit a natural survival response known as the ‘freeze response’ (Brantbjerg, 2021). To comprehend this freeze response, it is important to understand the underlying physiological mechanisms that drive the human defence cascade.

The stress response system of humans

Humans possess a stress response system that readies them to cope with threatening challenges. When confronted with a potential threat, the brain triggers a series of responses within the neural system (Ellis et al., 2006; Roelofs, 2017). The threatening stimulus is initially received by neurons in the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS includes the brain and the spinal cord, while the PNS comprises neurons throughout the rest of the body. The PNS can be further split into the somatic nervous system (SNS) and the autonomic nervous system (ANS) (Everly & Lating, 2019a). The ANS regulates various automatic physical functions and processes and stress-related signs (Beutler et al., 2022; Cardinali, 2018; Ellis et al., 2006). Activation of the ANS leads to a shift toward a state of biological and behavioural preparedness, characterized by an increased heart rate and blood pressure, heightened alertness and prioritized energy sources allocation to the brain to enhance cognitive functions (Ellis et al., 2006). The ANS is further divided into the sympathetic nervous system (SNS) and the parasympathetic nervous system (PSNS) (Roelofs, 2017). While the SNS dominates during the fight or flight responses, the PSN dominates during the freeze response (Niermann et al., 2017). The PSN prompts a shift characterized by heightened muscle tension, decreased heart rate and respiratory rates (Baldwin, 2013;

Kozlowska et al., 2015), diminished blood pressure, increased skin conductance (Beutler et al., 2022), redirection of energy and modulation of the immune response (Tsigos et al., 2020).

In response to a potentially threatening stimulus, arousal is the first step in activating the defence cascade (Kozlowska et al., 2015). The brain selects a defence cascade depending on the characteristics of the threat (Baldwin, 2013), which can result in either active defence responses like ‘flight’ or ‘fight’ or passive defence responses such as ‘freezing’ (Kozlowska et al., 2015). Different authors use various terms for the freeze response, including freeze-alert, freeze-fright, tonic immobility, collapsed immobility and faint (Baldwin, 2013; Bracha, 2004; Kozlowska et al., 2015; Roelofs, 2017). In this study the freeze response is divided into the initial ‘freeze response’, ‘tonic immobility’ and ‘collapsed immobility’. When any of these immobility’s are discussed, they are collectively referenced as the ‘passive defence response’ throughout this investigation.

When individuals confront a potentially threatening situation, the initial response is exhibiting a ‘freeze response’, which serves to heighten alertness and orientation toward the threat (Bracha, 2004; Kozlowska et al., 2015; Roelofs, 2017). This ‘freeze’ response is considered as an effective coping mechanism, as individuals minimize the risk of detection by avoiding movement, given that the visual cortex is primarily evolved for detecting moving objects (Bracha, 2004; Brantbjerg, 2021). Furthermore, the freeze response actively prepares individuals for further defensive responses due to the heightened attention and sensitivity for threat cues, priming their bodies for immediate action. Typically, this freeze response often lasts for only a few seconds and is followed by attempts to flee or fight. During a ‘flight or fight’ response, the sympathetic nervous system leads to an increased heart rate, increased respiratory rate and narrowed blood vessels in internal organs (Kozlowska et al., 2015). Besides, blood flow shifts depending on the chosen actions. For the ‘flight’ response, the blood flows toward the legs, while for the ‘fight’ response it flows towards the arms (Baldwin, 2013).

In situations where individuals feel trapped and believe there is no possibility of escape or the ‘flight or fight’ response have failed, tonic immobility may be triggered. Tonic immobility is characterized by the absence of movement in response to a threat as the brain is cancelling all movement. This immobility can be seen as a ‘flight or fight’ response put on hold and involves a coactivation of sympathetic and parasympathetic components. The sympathetic activation is similar to the flight or fight response, where individuals maintain a tensed muscle tone, even though humans experience temporary immobilization (Baldwin, 2013; Kozlowska et al., 2015). In the presence of the ongoing sympathetic activation, humans retain the capacity to flight or fight when the threat diminishes (Bracha, 2004; Brantbjerg, 2021). However, the parasympathetic system is simultaneously engaged. The parasympathetic system plays a role in reducing the heart rate. Additionally, it diminishes the respiratory rate (Baldwin, 2013; Kozlowska et al., 2015). The ultimate defence state of human physiological stress response is the condition of collapsed immobility. With facing extreme threats, the human body experiences diminished sympathetic activity, while the parasympathetic nervous system takes over. This transition is characterized by a significant drop in heart rate, clinically referred to as bradycardia (Baldwin, 2013).

The response individuals exhibit to a traumatic event is influenced by both the intensity and the duration of the experience. However, the same stressful situation can affect individuals differently, primarily due to variations in their genes, environment, social support from others and their physical and mental health (Cardinali, 2018). Kozlowska et al. (2015) have found that past experiences are a crucial factor as well. Individuals who have undergone multiple traumatic events may be more susceptible to triggering the defence response. This suggests that experiencing a traumatic event may cause alterations in the stress response system, subsequently resulting in modifications in arousal or reactivity, manifested through phenomena such as hypervigilance (Mash & Barkley, 2014). Hypervigilance is characterized by a continual monitoring of the environment (Fragkaki et al., 2016). Individuals displaying hypervigilance consistently manifest heightened sympathetic activation, as indicated by increased heart rate, blood pressure, and galvanic skin response (Kleshchova et al., 2019).

Current study

While there has been substantial research on trauma, there is a notable lack of comprehensive research on human immobility responses. Much of our knowledge about the human defence models derives from animal studies. While insights from animal studies enhance our understanding of human behaviour due to our common evolutionary path, caution is warranted given anatomical, cognitive and behavioural differences across species. Presuming similarity in human and animal psychophysiology may oversimplify findings (Beutler et al., 2022). Humans namely possess the capability to create subjective representations of their bodily states, a phenomenon that can activate the stress response system even in absence of a real external threat. This capacity remains uncertain in animals (Kozlowska et al., 2015). In this review, we aim to provide more clarity on which physiological mechanisms that underlie the passive defence response. Acknowledging the possible dissimilarities between animals and humans, this research exclusively focusses on human studies. Additionally, research predominantly focusses on the consequences of a traumatic event itself. This research, in contrast, seeks to delve into the evolution of trauma, highlighting the passive defence response. Exploring the physiological mechanisms involved in the passive defence is essential for understanding how individuals react to threatening situation and how it contributes to survival. As previously suggested by Roelofs (2017), identifying freezing as a potential marker for mental health issues could offer new insights, but further research was needed to confirm this. Investigating the physiological mecha in the freeze response among individuals could lead to a better understanding of individual differences in the human stress response system, which can potentially help forming personalized interventions.

As previously mentioned, in this review, we aim to delve deeper into the mechanisms that may lead to a passive defence response during a threatening event. While trauma-related symptoms have psychobiological underpinnings (Baldwin, 2013), this study specifically focusses on the biological part. The research question guiding this exploration is as follows: *'What physiological mechanisms underlie the passive defence response?'* Based on the findings from the literature search, the freeze response is expected to show signs of heightened muscle tension, decreased heart rate, respiratory rate and blood pressure, increased skin conductance, redirection of energy and modulation of the immune response (Baldwin, 2013; Beutler et al., 2022; Kozlowska et al., 2015; Tsigos et al., 2020).

Method

This study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines for systematic review and meta-analysis methodology in its execution and reporting (Page et al., 2021).

Search criteria

Based on a literature search, relevant physiological markers associated with the human stress response were identified, including heart rate, respiratory rate, blood pressure, muscle tension, skin conductance, energy supply and immune system (Baldwin, 2013; Beutler et al., 2022; Kozlowska et al., 2015; Tsigos et al., 2020). Subsequently, these physiological markers were incorporated into the search criteria to identify relevant articles for the systematic review. A systematic literature search was conducted using Web of Science and PubMed. A combination of the following key words was used: [(heart* OR muscle* OR blood* OR respirat* OR skin* OR energy OR “immune system”) AND (freez* or tonic immobility or collapsed immobility) AND (trauma* or PTSD or “post traumatic stress disorder”)]. There was no imposition of data restrictions to ensure the inclusion of all potentially relevant research studies. The search was conducted on November 6th 2023.

Selection criteria

All studies were required to be written in English and underwent peer review. Studies were selected for inclusion if they met the following criteria: 1) articles that investigate the physiological markers in relation to the passive defence response, 2) articles with participants who are either unexposed to trauma, exposed to trauma or diagnosed with PTSD. Exclusion criteria were: 1) articles not addressing a passive defence response, 2) articles conducted on animals and 3) systematic reviews and meta-analyses. After the initial analysis, an additional fourth exclusion criteria emerged: articles addressing dissociation rather than the freeze response or immobility. The rationale for this lies in the fact that defensive behaviour is not associated with dissociation. As articulated by Beutler et al. (2022), dissociation and immobility are related yet different constructs.

Study characteristics

Among 971 studies, 271 were duplicates. Once removed, 700 studies were further evaluated. A total of 27 studies met the inclusion criteria after initial search and remained to be analysed further. Two studies were excluded, because these studies were conference abstracts, six studies did not mention the physiological mechanisms that were identified in the literature search, one study had a wrong study design, seven studies focused on dissociation and one article was not available (see Figure 1). A total of ten studies were included in the final analysis. All these studies were experimental research designs.

Data extraction

A study coding spreadsheet was used to systematically gather data from each included study in the analysis. This spreadsheet encompassed comprehensive data, including basic study information, sample characteristics, the specific passive defence response under investigation, the method employed to measure this passive defence response, the means through which physiological mechanisms were provoked, and the tools utilized for measuring physiological responses, namely heart rate, respiratory rate, blood pressure, muscle tension and skin conductance. Notably, during the coding process, an observation emerged wherein the concept of muscle tension was absent in the research under consideration. The emphasis within experimental studies primarily centred on the phenomenon of body sway, thereby prompting its notation instead of muscle tension. Furthermore, the spreadsheet documented participants had been diagnosed with a trauma related disorder, elucidating the diagnostic criteria and methodologies applied in establishing these diagnoses. See Appendix. Coding System for the coding system.

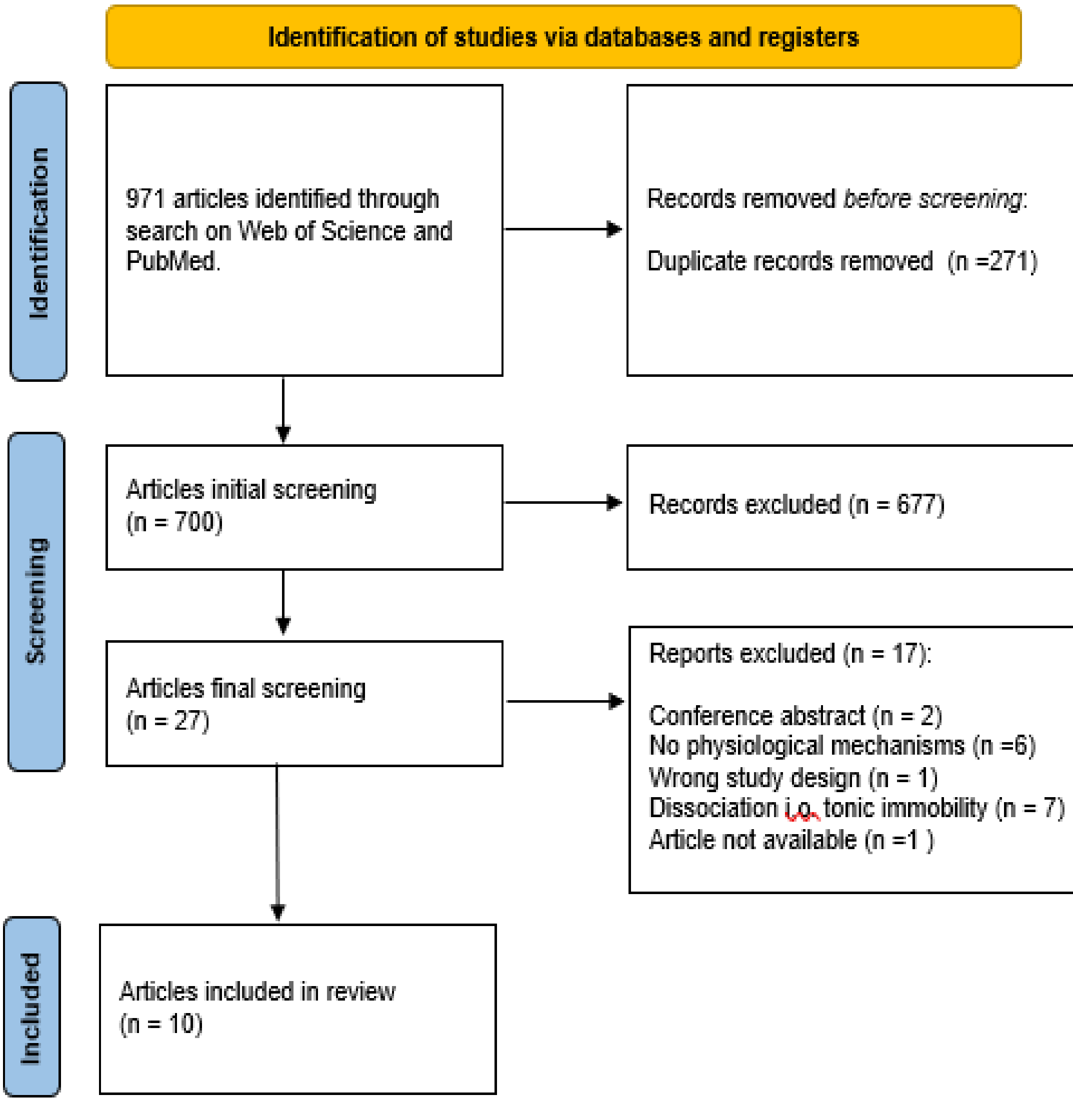

Figure 1. PRISMA Flowchart of literature search and study identification.

Results

General study characteristics

In total, ten articles have identified physiological mechanisms in humans during the freeze response. These studies exhibited a range of sample sizes, with participants counts varying from *n* = 3 to *n* = 78, resulting in a total of 324 participants being investigated. The mean age of the participants across these studies varied from 19.95 years to 44.64 years. Notably, two of the studies exclusively focused on female participants (Hagenaars et al., 2011; Rabellino et al., 2016), while the remaining studies included both males and females. Out of ten studies, eight focused on investigating the passive defence response in individuals who experienced a trauma (Adenauer et al., 2010; Alves et al., 2014; Fragkaki et al., 2017; Fragkaki et al., 2016; Hagenaars et al., 2011; Norte et al., 2019; Rabellino et al., 2016; Volchan et al., 2011). Among these, five studies specifically targeted patients diagnosed with post-traumatic stress disorder (PTSD) (Adenauer et al., 2010; Fragkaki et al., 2017; Fragkaki et al., 2016; Rabellino et al., 2016; Volchan et al., 2011). The assessment of PTSD in these studies was conducted using standardized tools such as the Clinician-Administered PTSD Scale (CAPS-IV), the PTSD Checklist-Civilian Version (PCL-C) or the diagnostic criteria outlined in the DSM-IV. In one study, traumatized individuals who had been exposed to trauma completed the Trauma History Questionnaire (THQ) (Alves et al., 2014), while another study used the Negative Life Experiences and Trauma Questionnaire as measuring tool (Hagenaars et al., 2011).

Regarding the six studies that addressed ‘tonic immobility’, all but one evaluated immobility by utilizing the Tonic Immobility Scale (TIS). One study did not employ a specific measurement for tonic immobility (Rabellino et al., 2016). In one study, subjective immobility was examined using the Likert Scale of International Affective Picture System (IAPS) rating system (Hagenaars et al., 2011). Additionally, three studies addressed the freeze response (Adenauer et al., 2010; Fragkaki et al., 2017; Hagenaars et al., 2015). Among these studies, one of these utilized both heart rate and body sway measurement to determine the freeze response (Fragkaki et al., 2017), while the other two studies exclusively focused on the heart rate as an indicator.

Physiological reactions were induced by diverse methodologies across the studies. Five studies employed visual stimuli in the form of pictures (Adenauer et al., 2010; Alves et al., 2014; Fragkaki et al., 2017; Hagenaars et al., 2015; Hagenaars et al., 2011), two studies employed auditory stimuli where participants listened to a script detailing their personal trauma (Norte et al., 2019; Volchan et al., 2011), another study directed participants to engage in cognitive tasks with variations with eye openness/closure (Fragkaki et al., 2016), one study utilized the Rubber Hand Illusion (Rabellino et al., 2016). Lastly, one study utilized social exclusion as the mechanism to provoke physiological mechanisms (Mooren & van Minnen, 2014).

All studies but one conducted an examination of heart rate (Adenauer et al., 2010; Alves et al., 2014; Fragkaki et al., 2017; Fragkaki et al., 2016; Hagenaars et al., 2015; Hagenaars et al., 2011; Mooren & Van Minnen, 2014; Norte et al., 2019; Volchan et al., 2011), with four out of ten studies additionally investigating body sway (Fragkaki et al., 2017; Fragkaki et al., 2016; Hagenaars et al., 2011; Volchan et al., 2011). One study examined skin conductance (Rabellino et al., 2016). The measurement of heart rate was accomplished through electrocardiogram in five studies (Adenauer et al., 2010; Alves et al., 2014; Mooren & Van Minnen, 2014; Norte et al., 2019; Volchan et al., 2011), while the remaining four studies utilized a polar band (Fragkaki et al., 2017; Fragkaki et al., 2016; Hagenaars et al., 2011, 2015). Regarding the assessment of body sway, all studies utilized posturography, employing a stabilometric platform. Lastly, skin conductance was measured using the Nexus-

10 & Bio Trace. See Table 1 and 2 for an overview of the general study characteristics and the physiological mechanisms.

Table 1

General Characteristics

Author(s) and year	**Sample size**	**PTSD *n* (mean age)**	**Trauma exposed *n* (mean age)**	**Control *n* (mean age)**	**Trauma measurement**	**Gender distribution**
Adenauer et al., 2010	78	39 (34.05)	20 (29.35)	19 (27.32)	CAPS-IV	37 males / 41 females
Alves et al., 2014	29	-	29 (20.7)	No control	Trauma History Questionnarie (THQ)	8 males / 21 females
Fragkaki et al., 2017	28	14 (41.64)	-	14 (44.64)	CAPS-IV	28 males
Fragkaki et al., 2016	24	12 (39.82)	-	12 (47.75)	CAPS-IV	24 males
Hagenaars et al., 2015	43	-	-	43 (19.7)	-	2 males / 42 females
Hagenaars et al., 2011	47	-	32 (N/A)	15 (20.6)	Negative Life Experiences and Trauma Questionnaire	50 females
Mooren & van Minnen, 2013	62	-	-	62 (19.95)	-	6 males / 56 females
Norte et al., 2019	17	17 (41.1)	-	No control	PCL-C	7 males / 10 females
Rabellino et al., 2016	3	3 (N/A)	-	No control	CAPS-IV	3 females
Volchan et al., 2011	33	18 (40.4)	15 (41.0)	No control	DSM-IV	18 males / 15 females

Noot. Control group = individuals who have not been exposed to a traumatic event

Heart rate

The studies reviewed present varied and some contrasting findings regarding heart rate responses. Adenauer et al. (2010) demonstrated distinct patterns in heart rate among different groups when exposed to affective visual stimuli (pleasant, neutral or unpleasant pictures). Unexposed individuals exhibited an expected heart rate response, marked by an initial deceleration to all pictures, with the most pronounced deceleration during exposure to unpleasant pictures (F (2, 36) = 4,76, $p < 0.01$). Regardless of the valence of the pictures, trauma exposed individuals reacted with a pronounced heart rate deceleration. Conversely, individuals diagnosed with PTSD displayed a weakened deceleration toward unpleasant pictures in the first two seconds (F (4, 150) = 3.74, $p < 0.01$) and a pronounced acceleration in the last two seconds (*LSD*, $p < 0.005$) compared to unexposed individuals and the trauma exposed, suggesting a rapid activation of a defence mechanism, preparing for escape without thoroughly assessing the situation. With regard to unexposed and trauma exposed individuals, Hagenaars et al. (2011) found somewhat different results. Whereas Adenauer et al. (2010) observed a similarity in heart rate among unexposed and trauma-exposed individuals when exposed to an unpleasant picture, Hagenaars et al. (2011) reported that individuals with single traumatic event (t (30) = -1.73, $p = 0.047$) and those with multiple traumatic events (t (28) = -2.06, $p = 0.024$) exhibited greater reduction in heart rate when viewing unpleasant pictures compared to unexposed individuals. Alves et al. (2014) also employed visual stimuli and categorized participants based on their trauma experiences (violent trauma and non-violent trauma). Only for those who experienced violent crime emerged a positive correlation between their trauma and changes in heart rate while viewing pictures ($\rho = 0.70$, $p = 0.005$). Notably, in the group of individuals who experienced violent crime, the severity of trauma impact as indicated by TIS scores, revealed a correlation with heart rate; lower TIS scores were associated with bradycardia, while higher TIS scores were associated with tachycardia.

This is align with the findings from Volchan et al. (2011), where they found a significant positive correlation between immobility scores and heart rate (ρ = 0.35, $p = 0.05$) for individuals exposed to traumas, but this contrasts with the study of Fragkaki et al. (2016) where a significant negative relationship between tonic immobility and heart rate was found (r = -0.48, $p = 0.024$), indicating that as tonic immobility increased, heart rate decreased. This was regardless of whether an individual had PTSD or was non-traumatized.

Similar to several other studies, Fragkaki et al. (2017) incorporated visual stimuli into their study. In this study, the participants were systematically classified into distinct groups, described as a participants control group and a PTSD group. An overall decrease in heart rate was observed when transitioning from pictures with a pleasant or neutral valence to those with an unpleasant valence (F (2, 52) = 4,103, $p = 0.022$). Notably, individuals with PTSD did not exhibit a statistically significant effect in heart rate changes depending on the emotional content of the presented stimuli. In contrast, the healthy control group exhibited a significant reduction in heart rate specifically in response to unpleasant pictures (F (38, 494) = 2.870, $p < 0.001$). This aligns with the findings of Hagenaars et al. (2015), where unexposed participants, akin to the healthy group in the study of Fragkaki et al. (2017), demonstrated a significantly lower heart rate while viewing unpleasant pictures compared to neutral ones ($p = 0.005$, one tailed) and pleasant ones ($p =0.08$, one tailed). The study of Mooren and Van Minnen (2014), where they investigated tonic immobility by unexposed individuals, they investigated the tonic immobility by social exclusion. However, the findings are aligned with the studies from Fragkaki et al. (2017) and Hagenaars et al. (2015). Unexposed individuals had a significantly lower heart rate during social exclusion (F (1, 52) = 22.36, $p < 0.001$). Finally, Norte et al. (2019) conducted an experiment involving auditory stimuli where participants listened to a script detailing their personal trauma to elicit physiological responses. The PTSD patients were categorized into two groups based on their TIS scores: a low TIS score group and a high TIS score group. The study revealed distinct heart rate reactions between these groups. Individuals with high TIS scores exhibited a larger and prolonged acceleration in heart rate compared to individuals with low TIS scores. Specifically, participants with low TIS scores demonstrated a rapid decline in heart rate shortly after the seventh second after exposure to the aversive noise. Conversely, individuals with high TIS scores displayed a sustained acceleration in heart rate, persisting until the forty-fifth second. These findings suggest that individuals with high TIS scores tend to experience a more robust and enduring increase in heart rate upon sudden exposure compared to those with low TIS scores. These findings are similar to Volchan et al. (2011) and Alves et al. (2014), where they found a positive correlation between TIS scores and heart rate.

Body sway

Hagenaars et al. (2011) conducted a study investigating body sway responses while participants viewed pictures categorized as pleasant, neutral and unpleasant. The researchers specifically analysed both anteroposterior (front to back) and mediolateral sway (side to side) sway movements. Their findings revealed significant main effect (F (4, 43) = 4.72, p = .003). of the emotional valence of the presented pictures on both anteroposterior- as mediolateral sway. This suggests that the emotional valence of these pictures influence postural stability. Further analysis indicated a significant difference in body sway between unpleasant pictures versus neutral pictures, whereas participants elicited reduced body sway to unpleasant pictures, observed in both anteroposterior sway (p = 0.035) and mediolateral sway (p < 0.001). Conversely, no significant differences were apparent between neutral and pleasant pictures (all p's > 0.05). These findings align with the results of Fragkaki et al. (2017), wherein they identified a significant interaction between PTSD and control groups regarding picture valence (pleasant, neutral and unpleasant) (F (2, 52) = 3.587, p = 0.035), suggesting divergent body sway responses induced by emotional pictures among individuals with PTSD compared to control group. PTSD patients did not exhibit significant differences in body sway in response to pictures of varying valences (F (2 , 26) = 0.756, p = 0.480), while the non-traumatized control group displayed a significant effect in body sway response to picture valence. Specifically, the control group showed a decreased body sway for unpleasant pictures comparted to neutral (p = 0.023) and pleasant pictures (p = 0.011). Fragkaki et al. (2016) investigated body sway in response to another stressor than pictures, namely eye closure. The choice of this stressor was motivated by its interference with hypervigilance, a symptoms commonly observed in PTSD patients. Hypervigilance involves constant monitoring for potential threats, and during eye, closure individuals lose the ability to scan their environment. In this method, participants stood on a stabilometric platform, while they were asked to focus on a monitor displaying a cross. The experimental phase involved four distinct conditions: 1) standing on the platform with eyes open, fixating on the cross, 2) standing on the platform with eyes closed, 3) standing on the platform with eyes open while engaging in a mental task of counting backward in steps of 7 and 4) standing with eyes closed while performing the same task. The researchers observed a significant interaction between vison (eyes open or closed) and group (PTSD patients or control group) (F (1, 20) = 13.977, p = 0.001), suggesting distinct responses to eye closure between PTSD patients and control group. Individuals with PTSD exhibited increased body sway compared to the control group. Furthermore, Fragkaki et al. (2016) extended their investigation beyond solely examining PTSD diagnoses by exploring the relationship between TIS scores and body sway. Notably, a significant negative correlation was observed, revealing that higher tonic immobility scores were associated with decreased body sway from eyes open to eyes closed (r = -0.76, p < 0.001). Volchan et al. (2011) are aligned with the results from Fragkaki et al. (2016), both showing a significant negative relationship between TIS scores and body sway after exposure to a trauma-related script ($\beta = -0.03$, $p = 0.01$), evident in both individuals diagnosed with PTSD and the non-traumatized control group. These findings from Volchan et al. (2011) somewhat echo Fragkaki et al. (2017), which noted decreased body sway in the healthy control group, but contrasted with the response seen in the PTSD group.

Skin conductance

The study conducted by Rabellino et al. (2016) was the singular investigation examining tonic immobility alongside skin conductance, where skin conductance measurements were taken during the Rubber Hand Illusion (RHI). The RHI is a perceptual illusion that manipulates the brain's interpretation of visual, tactile, and proprioceptive inputs related to one's own hand. In this method, participants are instructed to focus on a realistic rubber hand while their real hand is hidden, and both hands are simultaneously brushed. This manipulation induces temporary distortion in the participants' perception of their own body. According to the researchers, the RHI elicits distress, tonic immobility, and autonomic responses in individuals with trauma-related disorders. Notably, a progressive increase in skin conductance was observed in the two participants throughout the experiment. It is noteworthy, however, that the study's presentation of findings lack statistical analyses.

Table 2

Physiological Mechanisms

Author(s) and year	**Passive defence response**	**Measurement**	**Inducation of physiological mechanisms**	**Heart rate (measurement)**	**Body sway (measurement)**	**Skin conductance (measurement)**
Adenauer et al., 2010	Freeze response	Heart rate	Visual stimuli	Yes (ECG)	No	No
Alves et al., 2014	Tonic immobility	TIS	Visual stimuli	Yes (ECG)	No	No
Fragkaki et al., 2017	Freeze response	Heart rate / body sway	Visual stimuli	Yes (polar band)	Yes (stabilometric platform)	No
Fragkaki et al., 2016	Tonic immobility	TIS	eye openness/closure	Yes (polar band)	Yes (stabilometric platform)	No
Hagenaars et al., 2015	Freeze response	Likert Scale of IAPS rating system	Visual stimuli	Yes (polar band)	No	No
Hagenaars et al., 2011	Subjective immobility	Heart rate	Visual stimuli	Yes (polar band)	Yes (stabilometric platform)	No
Mooren & van Minnen, 2013	Tonic immobility	TIS	Social exclusion	Yes (ECG)	No	No
Nòrte et al., 2019	Tonic immobility	TIS	Auditory stimuli	Yes (ECG)	No	No
Rabellino et al., 2016	Tonic immobility	No measurement	Rubber Hand Illusion	No	No	Yes (Nexus-10 & Bio Trace)
Volchan et al., 2011	Tonic immobility	TIS	Auditory stimuli	Yes (ECG)	Yes (stabilometric platform)	No

Noot. TIS = Tonic Immobility Scale, ECG = electrocardiogram

Discussion

In this review, we aimed to identify the physiological mechanisms that underlie the passive defence response. Several physiological mechanisms were identified in response to stress. These include heightened muscle tension, decreased heart rate and respiratory rates, diminished blood pressure, increase in skin conductance, redirection of energy and modulation of the immune response (Baldwin, 2013; Beutler et al., 2022; Kozlowska et al., 2015; Tsigos et al., 2020). Among the ten selected studies, heterogenous was found on several characteristics, including participants characteristics and methodological measurements.

Participant characteristics

Eight out of ten studies have focused on investigating the passive defence response among individuals with a trauma-related disorder, with a particular emphasis on patients with PTSD in six of the studies (Adenauer et al., 2010; Fragkaki et al., 2017; Fragkaki et al., 2016; Norte et al., 2019; Rabellino et al., 2016; Volchan et al., 2011). Results from this review show that individuals who have undergone a traumatic event exhibit altered patterns compared to the control group, characterized by fluctuations and variations from the expected physiological reactions. This aligns with the findings from Williamson et al. (2015), who identified differences in processing the environmental stimuli among individuals with PTSD compared to those without PTSD. Individuals with PTSD are likely to have sensory processing disturbances, leading to discernible differences in stress responses among those individuals. These differences are noteworthy, since investigating the passive defence response in individuals with PTSD may lead to biased data, whereas studies with only individuals with PTSD possibly show contradictory results.

Additionally noteworthy is the absence of specifically looking at gender differences in the stress response among the selected studies. In eight of the ten studies, a greater number of female participants were included (Adenauer et al., 2010; Alves et al., 2014; Hagenaars et al., 2015; Mooren & Van Minnen, 2014; Norte et al., 2019; Volchan et al., 2011), and notably, two studies exclusively focused on females (Hagenaars et al., 2011; Rabellino et al., 2016). The study of Hagenaars et al. (2011) stands as the sole study deliberately selecting only female participants to achieve a homogeneous study group. The overrepresentation of females in these studies is not surprising, as existing research on patients with PTSD reveals that females are twice as likely to develop PTSD compared to males. Moreover, their symptoms tend to endure up to four times longer than those experienced by males (Mash & Barkley, 2014). Consequently, the higher number of female participants in these studies is understandable, as it is generally easier to recruit females than males. Nevertheless, it is essential to acknowledge and consider this gender bias in the interpretation of the findings. As highlighted by Verma et al. (2011), men and women tend to exhibit distinct reactions to stress, where adult men exhibit greater autonomic responses compared to adult women. This distinction is noteworthy, since studies with remarkable percentage of more females or males may lead to biased data, whereas studies with more females possibly shown less significant findings.

Methodological measurements

In human research studies, not all of the previously mentioned physiological responses have been adequately measured. While for the direction of energy and modulation of the immune response direct measurements pose challenges, measurements for respiratory rate, muscle tension and blood pressure are feasible. The selected studies predominantly focussed on examining the phenomenon body sway instead of muscle tension. However, it is interesting to note that muscle tension is readily measurable for research through surface electromyography (sEMG) as showed by Mondelli et al. (2014). Surface electromyography involves a painless placement of surface electrodes on the skin to analyse the electrical signals, whereby electrical activity can be captured both during exercise and rest (Mitchell, 2016). For this reason, sEMG could be a suitable technique for assessing muscle tension related to the passive defence response. However, the selected studies may have prioritised the examination of body sway through a stabilometric platform rather than directly measuring muscle tension using electrodes. This preference is likely due to the advantages of a stabilometric platform, which allows for capturing the entire body including the trunk, thigh, and shank (Chiari et al., 2002). This approach contrasts with the superficial targeting of muscles using electrodes. Moreover, body sway is considered as indirect sign of muscle tension. There is a significant relation between muscle tension and body sway, whereas tense body posture implies increased muscle tone (Hagenaars et al., 2014). Given the association between body sway and muscle tension, and the comprehensive capturing of all body movements provided by a stabilometric platform, researchers may have chosen for the assessment of body sway in their investigation.

Moreover, alongside muscle tension, additional physiological parameters such as respiratory rate and blood pressure present accessible tools for measurements as well. Clinically, the assessment of respiratory rate encompasses various methodologies, including spirometry, capnometry, and pneumography. However, these techniques demonstrate disadvantages for research. All these techniques are susceptible to interference caused by contact and lack wireless functionality. Notably, their cost are high, and more importantly, these methodologies are impractical for testing stress, as highlighted by Liu et al. (2019). Stress testing can influence an individual’s breathing patterns, rendering the capture of accurate and synchronized data more challenging under these conditions. These tools may not fully address the complexities introduced by the dynamic nature of breathing during stress testing. This might explain the absence of respiratory rate measurements in studies exploring the passive defence response.

Furthermore, Ogedegbe and Pickering (2010) mention multiple techniques to measure blood pressure, including the auscultatory method, the oscillometric technique, ultrasound techniques and the finger cuff method of Penaz. Comparable to the respiratory rate assessment, each of these techniques possesses distinct limitations, as a result of which not all techniques are suitable for measuring blood pressure during a passive defence response. All methods require physical manipulation or contact, potentially disturbing the freeze response.

Nevertheless, the Zephyr BioHarness underwent testing to determine the accuracy of heart rate and respiratory rate. This wireless physiological monitoring device, resembling a chest strap, eliminates interference issues. The device encompasses the monitoring of physiological parameters such as heart rate and respiratory rate. Additionally, this device has proven instrumental in gaining valuable insights how individuals move and use energy during activities, with researchers finding it to be reliable (Nazari et al., 2019). Consequently, the Zephyr BioHarness emerges as a promising device for evaluation physiological parameters during the passive defence response in humans.

Heart rate

The heart rate stands out as a crucial physiological indicator in the context of the passive defence response, with selected studies revealing conflicting heart rate responses. Six studies found an overall expected decrease in heart rate during the passive defence response (Adenauer et al., 2010; Fragkaki et al., 2017; Fragkaki et al., 2016; Hagenaars et al., 2015; Hagenaars et al., 2011; Mooren & Van Minnen, 2014), whereas three studies found an overall increase (Alves et al., 2014; Norte et al., 2019; Volchan et al., 2011). Moreover, conflicting findings were observed concerning the correlation between heart rate and tonic immobility.

While two studies reported positive correlations between trauma impact or immobility scores and heart rate (Alves et al., 2014; Volchan et al., 2011), Fragkaki et al. (2016) observed a negative relationship. Importantly, these variations were exclusively identified in individuals who have undergone a traumatic event. Intriguingly, a distinct trend was evident among those not exposed to trauma, all consistently displaying a decrease in heart rate during the passive defence response.

The observed inconsistencies in heart rate among individuals exposed to trauma may be influenced by small sample sizes and the methodologies employed to provoke physiological response. The limited sample sizes (ranging from n = 17 to n = 33) contribute to low external validity, as a small sample may not adequately represent the broader population. Furthermore, the disparities in findings could also be attributed to methodological differences. Norte et al. (2019) and Volchan et al. (2011) stand out as the only studies that examined tonic immobility using an auditory stimuli. In both studies, participants listened to a script detailing their personal trauma. An auditory stimulus, particularly one involving the narration of personal traumatic experiences, may potentially elicit a different defence response compared to visual stimuli depicting an unpleasant picture.

However, these variations may also suggest complexities in physiological reactions among individuals affected by trauma. The observed inconsistencies could imply that individuals exposed to trauma manifest different responses, making it challenging to identify any discernible trends. This aligns with findings from Williamson et al. (2015), who observed that individuals who have undergone a traumatic event seem to process environmental stimuli differently.

Body sway

Studies that assessed body sway demonstrated conflicting body sway responses as well. The studies who examined participants with no trauma history (control group) found somewhat similar results. Hagenaars et al. (2011), Fragkaki et al. (2017) and Volchan et al. (2011) found overall reduced body sway during the passive defence response, whereas Fragkaki et al. (2016) found no reduced body sway in the control group while eye closure, but they did found reduced body sway when participants reported high TI scores. However, the studies emphasized varying body sway patterns between individuals with PTSD. Three studies investigated the freeze response with individuals with PTSD. Among these three studies, Fragkaki et al. (2017) found no significant differences in body sway response for PTSD patients, whereas Fragkaki et al. (2016) reported an increase in body sway for PTSD patients. The conspicuous nature of these findings is noteworthy, particularly considering that the same researcher conducted the investigations. However, they did not provide an explanatory account for the discovering a significant finding now as opposed to in their earlier investigation. In contrast, Volchan et al. (2011) found reduced body sway in PTSD patients. Notably, their assessment of body sway occurred after the stressor, rather than during it, raising the possibility that reactivity may occur within this timeframe, distinct from risk assessment and freezing behaviours. The inconsistencies found in the studies investigating PTSD patients can also results from the distinction between studies. Fragkaki et al. (2017) investigated the initial ‘freeze response’, while Volchan et al. (2011) investigated the tonic immobility. According to Fragkaki et al. (2017), tonic immobility might be linked to the onset of PTSD, whereas the freeze response could be associated with the maintenance of PTSD. These different defence response possibly lead to different physiological outcomes. However, the observed inconsistencies may suggest once again that individuals exposed to trauma manifest different responses, making it challenging to identify any discernible trends.

Strengths and limitations

The potential influence of selection bias on the results of this systematic review is acknowledged. Much of the existing research on trauma is primarily conducted on individuals diagnosed with trauma-related disorders (Baldwin, 2013). However, individuals who have received a diagnosis may have more severe or chronic symptoms, and their experiences may not fully reflect the range of responses to traumatic events. Moreover, they might not represent those who do not seek clinical assistance or do not receive formal diagnoses, despite experiencing trauma. Additionally, studying the freeze response is challenging due to the inherent difficulties in examining the traumatic experiences as they occur (Ataria, 2015). This may result in limited data and potential inaccuracies in assessing the phenomenon.

This current review has several limitations. First, there is a limitation related to selection bias, given the challenges of investigating the human response in real traumatic contexts (Ataria, 2015). The ethical implications of conducting research that elicits past traumatic experiences in patients raise legitimate concerns. Due to these concerns, there may be a sufficient number of patients who choose to abstain from participating in trauma-related research. Moreover, there may be individuals who have never sought help despite experiencing severe symptoms, and these individuals would be excluded from the research. Hence, these results may not represent the whole population of individuals with trauma experience.

Additionally, both the examination of the passive defence response using the TIS and employing heart rate measurements pose limitations in research. In experimental studies wherein the heart rate response serves as an indicator of the freeze response can be questionable. Despite expectations that the heart rate response would decrease when facing a threat, conflicting outcomes in this review prompt reflection on the validity of this measurement. In this review, certain studies have revealed that individuals do not always exhibit a decline in heart rate (Alves et al., 2014; Norte et al., 2019; Volchan et al., 2011). As previously mentioned, these atypical responses are not surprising, given that PTSD patients seem to process environmental stimuli differently (Williamson et al., 2015). Consequently, the question emerges regarding the efficacy of these studies in accurately assessing the passive defence response through the utilization of heart rate measurements, in particular for PTSD patients.

However, the utilization of the Tonic Immobility Scale (TIS) concerns limitations as well. The TIS is self-report assessment tool, that was initially designed to quantify the occurrence and intensity of tonic immobility experienced by female survivors of sexual assault. Following its inception, adaptions were introduced to broaden its applicability across different traumatic scenarios and enable its utilization within experimental studies. However, reliance on self-report instruments may introduce limitations due to individuals' incomplete self-awareness when assessing tonic immobility (McDonald, 2008). Moreover, recall bias is inevitable, as retrospective reports may tend to underestimate reports of tonic immobility, particularly when recalling experiences from an extend period ago (Benjet et al., 2015).

Several notable strengths highlight the relevance of this review. It provides a comprehensive understanding of the underlying physiological mechanisms in the passive defence response. The review systematically examined a range of studies, that delves into specific measurements and outcomes. This approach has led to the identification of both similarities as differences across the selected studies. Moreover, this review plays an essential role in identifying a significant gap within the existing literature concerning the physiological mechanisms involved in the human freeze response. By shedding light on the lack of certain physiological mechanisms, the review serves as an encouragement towards further research. Moreover, these findings underscore the complexity of passive defence responses and the influence of a traumatic event on physiological reactions among individuals exposed to trauma. The observed divergent responses imply that individuals who have undergone a traumatic event may exhibit diverse reactions. Adenauer et al. (2010) suggest that individuals undergoing trauma exhibit rapid activation of the defence mechanisms, preparing for escape without thoroughly assessing the situation. However, this response may vary among individuals who have undergone a traumatic event, as highlighted by Williamson et al. (2015), who found that that individuals who have undergone a traumatic event appear to process environmental stimuli differently. Recognizing that individuals may exhibit different patterns after experiencing a traumatic event can be valuable, as it offers potential insights for designing individual interventions.

Conclusion and future research

In this review, we examined the physiological mechanisms underpinning the passive defence response. The results suggest different patterns in physiological responses between individuals with and without trauma exposure. Specifically, individuals without trauma exposure typically exhibit a reduction in heart rate and body sway. On the contrary, these patterns are not consistently observed in individuals exposed to trauma. This review emphasizes the presence of discernible variations in the physiological mechanisms, highlighting the contrasting patterns in individuals exposed to trauma. However, these inconsistencies in physiological underpinnings may also possibly be influenced by small sample sizes, variations in the terminology used to describe the freeze response, and differences in the provocation of physiological mechanisms.

It is important to acknowledge that some physiological mechanisms, such as muscle tension, respiratory rate, and blood pressure during the passive defence response, have not been examined yet. This gap emphasizes the need for further empirical studies. For further research, I recommend focusing on methodologies characterized by limited interference to enhance reliability. Prominent examples include the Zephyr BioHarness or image-based monitoring methods. Image-based monitoring methods have the potential to measure vital signs utilizing non-contact sensors. A systematic review by Harford et al. (2019) revealed the significance of monitoring heart rate and respiratory rate through video images, highlighting agreement with clinically acceptable limits under experimental conditions. Finally, I suggest that in examining the physiological mechanisms of individuals who have undergone a traumatic event, researchers should assess responses at both individual and group levels. This approach is essential, as individuals may manifest divergent physiological responses during the passive defence reaction following exposure to a traumatic event.

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Appendix. Coding system

1. (first two) Author(s) and year
2. Sample size
3. Participants with PTSD (including mean age)
4. Participants trauma exposed, but no PTSD (including mean age)
5. Participants control group (including mean age)
6. Gender distribution
7. Trauma measured
8. Passive defence response
9. Passive defence response instrument
10. Inducation of passive defence response
11. Heart rate
12. Measurement of heart rate
13. Respiratory rate
14. Measurement of respiratory rate
15. Blood pressure
16. Measurement of blood pressure
17. Body sway
18. Measurement of body sway
19. Skin conductance
20. Measurement of skin conductance