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Exploring the Subjective Experience of Virtual Reality: The Relationship between Consumers' Internal Bodily Feelings and the Senses of Presence and Body Ownership

par
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Résumé

La présence et l'expérience d'appropriation corporelle (*experience of body ownership* - EBO) se sont révélées cruciales dans l'évaluation des expériences de réalité virtuelle. Toutefois, les recherches précédentes portaient principalement sur la stimulation externe et ont ignoré l'influence des sensations corporels internes sur l'expérience du consommateur dans les environnements virtuels. À travers deux études, nous comblons cette lacune en utilisant une approche interdisciplinaire, visant à explorer l'impact des sensations qui proviennent de signaux corporels internes sur l'expérience de réalité virtuelle (RV) des consommateurs. Plus spécifiquement, nous nous basons sur les études en interoception (sens des changements physiologiques dans le corps) pour explorer deux éléments constitutifs de l'expérience de réalité virtuelle : la présence et l'appropriation corporelle.

La première étude utilise une tâche de suivi pour calculer l'interoception et étudier l'impact du modèle des trois niveaux d'interoception (précision, sensibilité et conscience) sur la perception de la présence et l'EBO, dans deux conditions de réalité virtuelle différentes. Une condition était un jeu expérientiel dans lequel le participant était libre d'interagir avec l'environnement virtuel sans pression de performance. L'autre condition était un jeu de prise de décision dans lequel le participant devait exécuter une tâche visuo-spatiale dans des délais très courts. Les résultats de l'étude fournissent, pour la première fois, l'évidence que la conscience (mais pas la précision ou la sensibilité) est corrélée avec la présence et avec l'appropriation corporelle, mais seulement pendant le jeu expérientiel. Nous suggérons que la conscience interoceptive, en prenant en compte la mesure dans laquelle la confiance prédit la précision interoceptive, peut inférer plus précisément comment les sensations interoceptives ont un impact sur le sens de la présence et l'EBO du consommateur pendant une expérience de réalité virtuelle. L'étude a toutefois présenté des limites méthodologiques qui ont soulevé deux questions principales : 1) Est-ce que les résultats ont pu être affectés par la méthode utilisée pour calculer l'interoception? 2) Est-ce que l'absence de corrélation dans la tâche de prise de décision a été causée non seulement par la méthode utilisée, mais également par le type de tâche dans le jeu de prise de décision?

La deuxième étude prend ensuite en considération les limitations méthodologiques soulevées pour explorer la manière dont la relation entre l'interception, la présence, l'EBO et la performance décisionnelle varie en fonction de la méthode utilisée pour calculer l'interoception (c.-à-d. une tâche de détection VS. une tâche de suivi cardiaque). En utilisant les deux mêmes conditions que celles utilisées dans la première étude, plus une troisième condition (un jeu de décision en réalité virtuelle basé sur des capacités de prédiction motrices intuitives), nous montrons que les différences entre les variables résultantes de la tâche de suivi et de la tâche de détection conduisent également à des associations différentes entre l'interception et les variables de présence, l'EBO et la performance décisionnelle. Nos résultats indiquent que les processus psychologiques sous-jacents spécifiques à la tâche de suivi ou de détection (également soutenus par la réaction physiologique des participants et les réponses subjectives à ces tâches) peuvent non seulement créer des différences entre chacun des niveaux d'interoception, mais semblent aussi être associés avec les caractéristiques spécifiques des différentes expériences de réalité virtuelle.

Ensemble, ces deux études contribuent à la compréhension des aspects de la cognition incarnée dans l'expérience de réalité virtuelle au-delà des stimuli sensoriels externes, fournissant des informations sur la complexité du phénomène, ainsi que des recommandations méthodologiques pour l'étude d'informations multisensorielles intégratives (c.-à-d. externes et internes) dans la recherche en comportement du consommateur.

Mots clés: Expérience de Réalité Virtuelle; Cognition Incarnée; Interoception; Présence; Appropriation Corporelle

Méthodes de recherche: Conception Expérimentale, Mesures Psychophysiologiques, Recherche Corrélationnelle, Inventaire d'Auto-évaluation

Abstract

Although presence and body ownership have been shown to be crucial in the evaluation of virtual reality (VR) experiences, previous research has mostly focused on external stimulation and left aside the exploration of how internal bodily feelings can modulate consumer experience in virtual environments. Here, we address this gap by following an interdisciplinary effort to explore in two studies the impact of the feelings that arise from internal bodily signals on consumers' virtual reality (VR) experience. More specifically, we draw from the cognitive neuroscience research in interoception (i.e., the sense of physiological changes in the body) to explore two of the building blocks of VR experience: presence and subjective experience of body ownership (EBO).

Study 1 uses the tracking task to calculate interoception and investigate the impact of the three-level model of interoception (i.e., accuracy, sensibility, and awareness) on Presence and EBO in two different VR conditions: An experiential game in which the participant was free to interact with the virtual environment without pressure to perform and a decision-making game in which the participant had to perform a visual-spatial task under time-pressure. Findings from the study provide, for the first time, evidence that awareness (but neither accuracy nor sensibility) is positively correlated with presence and EBO, but only during the experiential game. We suggest that awareness, by taking into consideration the extent to which one's confidence predicts his or her interoceptive accuracy, can more precisely infer how interoceptive feelings may have an impact on the consumers' sense of presence and EBO during a VR experience. However, the methodological limitations of the study raised two main questions: 1) Could the results be influenced by the method used to calculate interoception? 2) Could the lack of correlation in the decision-making task have been caused not only by the method used, but also by the type of task in the decision-making game?

Study 2 then takes into consideration the methodological limitations of Study 1 to explore how the relationship between interoception (especially awareness), presence, EBO, and decision-making performance vary according to the method used to calculate interoception (i.e., tracking task vs. detection task). By using the same two conditions that

were used in Study 1 plus a third condition (a decision-making VR game focused on intuitive motor prediction abilities), we provide evidence that the differences between tracking and detection task outcome variables also lead to different associations between interoception and the variables of presence, body ownership, and decision-making performance within each condition. Our findings indicate that underlying psychological processes specific to either the tracking or detection task (also supported by participants' physiological reactions and subjective responses to these tasks) may not only create differences in each of the levels of interoception but they also seem to be associated with the specific characteristics of different VR experiences.

Together, these two studies contribute to the understanding of embodied cognition aspects in VR experience beyond external sensorial stimuli, providing insights into the complexity of the phenomena well as methodological recommendations for the study of integrative multisensorial information (i.e., external and internal) in consumer behavior research.

Keywords: Virtual Reality Experience; Embodied Cognition; Interoception; Presence; Body Ownership.

Research methods: Experimental Design, Psychophysiological Measures, Exploratory Correlational Research, Self-report Inventory.

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Acknowledgements

A question is a pursuit, an invitation to envision and explore a series of possibilities, to struggle and empathize and doubt and believe. The question moves, whereas our sense of what an answer is can often be static, a stopping point.

Tracy K. Smith

The challenge that one faces when deciding to become a Ph.D. is rarely described in real measures. Maybe, since it just cannot be measured, it has to be experienced. The nights awake, the lack of sleep, the frustration that so often hits the researcher, these are all far from myths. But it is in these moments of darkness and fatigue experienced by the pupil that the guidance and empathy of a real wise master are most important. And I am extremely proud to say that I was able to count on two of them, Professors Sylvain Sénécal and Danilo Dantas. I have no words to adequately express my gratitude for your support, motivation, and guidance throughout all these years and way before the Ph.D. program. The opportunities you gave me are priceless. Moreover, you both went above and beyond to make sure I had all the support possible. For that, you have my deepest respect and gratitude. May you be able to keep such wisdom to help others in stormy moments just as you did for me.

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Introduction

In recent years, virtual reality (VR) companies (for both content creation and technology development) have experienced a fast growth due to unparalleled advance in technology. This growth is promoting and popularizing VR as the most promising form of technology for the development of electronic-based entertainment and education (Zyda 2005; Olasky et al., 2015), with projected worldwide consumer revenues of nearly $19 billion by the end of 2021 (SuperData Research Inc, Nielsen, 2018), propelled by investment of major tech firms such as Facebook, Sony, HTC, Microsoft, Google, and SpaceX.

Unique in comparison to other media, VR is able to provide responsiveness to interaction, flexibility, and diverse interactive forms of experiences. In fact, Riva et al. (2016) suggest that VR is the "ultimate communication medium," "an embodied technology" in which user experience is induced by presenting both a virtual world and a virtual body. Thus, VR relates to two crucial factors needed to induce the illusion that a virtual experience is real: (1) the feeling of presence (i.e., the feeling, sense or state of "being there" in a space or environment) and (2) the feeling of body ownership (i.e., perceiving another body or part of it as your own body, and thus creating the illusion that the bodily sensations in the other body are actually felt by oneself) (Gallagher, 2000; Liang et al., 2015). Moreover, by using multisensory stimulation, VR has the potential to induce a subjective sense of "presence" and an illusion of body ownership even when the person is aware that the experience is not real (Gallagher, 2000; Kilteni, Maselli, Kording & Slater, 2015), creating emotional responses that are as effective as those induced by real life events (Riva et al., 2016).

In general, sensations of body ownership have been previously observed through physiological reactions such as body temperature (Moseley et al., 2008), galvanic skin response (Petkova & Ehrsson, 2008), and heart rate (Slater et al., 2010). Moreover, the current state of the field supports the view that the modulation of body ownership sensations is congruent with an integrative perspective of body-related sources of information, which combine both external ("exteroceptive") and internal ("interoceptive") bodily signals (Filippetti & Tsakiris, 2017). Thus, by adopting an integrative perspective that takes into consideration not only external stimuli but also internal bodily sensations, a more recent stream of research in VR is attempting to better explain how virtual experiences can elicit a variety of emotional states (Geslin, Bouchard & Richir, 2011) and enhance both partial (Tsakiris, Tajadura-Jiménez, & Constantine, 2011) and full-body illusions (Slater et al., 2010; Banakou, Groten, Slater, 2013).

However, despite the growing evidence supporting the role of internal bodily feelings to explain VR experiences, until now the development of the field has been mostly focused on understanding the sense of spatial presence by exploring users' interaction with the virtual environment by simulating external environmental cues via audiovisual or, more recently, tactile stimulation. Thus, very little has actually been done so far to understand body ownership and especially presence in VR experience through internal sensations or by integrating external and internal stimulations to induce a higher sense of "self" (Tsakiris, 2017; Riva et al., 2016).

Only a few studies have so far provided evidence of the behavioral impact of internal bodily feelings and their integration with external stimuli on subjective experiences of body ownership (Tsakiris Tajadura-Jiménez, & Constantine, 2011; Suzuki et al., 2013; Aspell et al., 2013; Crucianelli et al., 2013; van Stralen et al., 2014). Although two of them used virtual reality to induce the sense of body ownership (Suzuki et al., 2013; Aspell et al., 2013), none of these studies have investigated the impact of interecoptive feelings on the experience of presence (see however Seth, Suzuki, & Critchley, 2012 for a theoretical model that suggests a neuroanatomical correlation between presence, agency, and interoception). Therefore, we aim at investigating how interoception (i.e., the ability to sense physiological conditions of the body; Craig, 2015) is associated with presence and body ownership in the context of VR experience.

The exploration of interoceptive feelings is crucial for better understanding of consumers' experiences in VR since it is the integration of sensations that come from our bodies that enables the foundation of subjective feelings, emotions, and self-awareness (Craig, 2009). Contemporary views on interoception suggest that the insular cortex plays a multifunctional role by not just integrating interoceptive signals in the brain but also using these signals to generate our emotional experiences (Craig, 2009; Critchley & Seth, 2012; Seth, 2013; Gu, et al., 2013). Interestingly, these recent findings seem to add to early indications that the insular cortex contains a viscerotopic map of the body (Cechetto & Saper, 1987). Moreover, contemporary research in neuroscience is also pointing to the idea that the brain works as an active inference generator that uses previous experiences to anticipate future sensorial input (i.e., interoceptive predictions) and influence our perception of the world (Barret & Simons, 2015). Thus, because VR experiences are also influenced by the mismatch between expected and actual sensorial input (Reason, 1978; Pauna et al., 2018), we believe that exploring the role of interoceptive sensations in VR is crucial to understand how humans perceive a virtual environment, consequently leading to the optimization of virtual experiences.

The main goal of this research is therefore to explore the association between the consumers' internal bodily feelings and the senses of presence and body ownership during VR experiences. However, we also explore the impact that interoception may have on decision-making performance. This idea is based on previous studies that have provided evidence of a positive correlation between interoception and better outcomes in both emotional regulation and intuitive decision-making tasks (Kirk, Downar, & Montague, 2011; Werner et al., 2013; Werner et al., 2009). Moreover, VR games, in contrast to traditional video games, can be either performance-oriented (i.e., when the player has a task or decision to perform under a certain type of pressure, such as time constraints – traditional gaming experience) or experiential-oriented (i.e., when participants focus merely on interacting with the virtual environment, without feeling any pressure to perform any specific task – similar to an interactive film). Taking into consideration these types of experiences we decided to also test if these different gaming experiences could be differently influenced by interoceptive abilities.

This study also differs from previous efforts in that it explores interoception according to its three-level model (Garfinkel and Critchley., 2013; Garfinkel et al., 2015), which was proposed as a solution to disentangle the concepts used interchangeably in previous research. The model clearly defines interoceptive accuracy (how objectively one can detect his or her bodily changes, measured via heartbeat tasks), sensibility (subjective tendency to feel and believe in one's perception of bodily sensations, measured via self-reported tools), and awareness (the metacognitive awareness of interoceptive accuracy, measured by the extent to which one's sensibility predicts one's accuracy).

Exploring the association between presence, body ownership, and the three levels of interoception is important since previous studies have shown that accuracy, sensibility, and awareness are distinct or partially distinct from each other (Meessen et al., 2016; Forkmann et al., 2016). Still, to the best of our knowledge, only three studies have explored the relationship between interoception (accuracy only) and body ownership. The first one was done by Tsakiris, Tajadura-Jiménez and Costantini (2011), who performed a median split analysis to provide evidence that participants with low interoceptive accuracy (via detection task) would experience higher levels of body ownership illusion. The two other studies (Suzuki, et al., 2013; Aspell et al., 2013) went a step further and provided evidence that body ownership experiences can be enhanced by synchronous cardio-visual feedback with the actual heartbeat of participants. However, to the extent of our current investigation, no study has yet explored the relationship between the three levels of interoception and the senses of presence and body ownership.

Moreover, previous studies have also pointed out methodological limitations within the two main methods of calculating interoception (i.e., tracking and detection tasks) as well as differences in their outcome variables probably caused by divergent underlying attentional processes required to perform them (Forkmann et al., 2016; Ring & Brener, 2018). Thus, because of this complexity involved in the calculation of interoception and the lack of conclusive evidence about the relationship between the three levels of interception and presence or body ownership, we also explore how these core methodological aspects can impact the relationship between the levels of interception and the senses of presence and body ownership.

Thus, in Study 1, we used the heartbeat tracking task to provide evidence for the first time that interoceptive awareness, but not accuracy or sensibility, is correlated with presence and body ownership when participants played experiential games (vs. decision-making games). In Study 2, we built upon the findings and limitations of Study 1 to show that the methods applied to calculate the interoception can have an impact on the association between interoception, presence, body ownership, and decision-making. Moreover, the results of Study 2 also indicate a possible association between the underlying attentional processes specific to each of these methods and the characteristics of each VR game.

This research, therefore, provides two main contributions to consumer behavior research related to how consumers are affected by their senses (Krishna, 2012): 1) It extends our understanding of core aspects in Virtual Reality (i.e., presence and body ownership) by exploring how feelings that arise from both internal and external bodily signals interact with other senses to shape our experiences (Krishna and Schwarz, 2014); 2) It provides methodological recommendations that can contribute to the consolidation of a neurophysiological basis of well-established psychological theories (e.g., embodied cognition) that serve as a basis for various consumer behavior studies (Krishna and Schwarz, 2014).

Chapter 1: Theoretical framework

Since its beginning, consumer behavior research has been closely linked to psychology, a relationship that became even stronger with the emerging importance of topics such as consumer experience, irrationality, decision-making, and sensory marketing. Krishna and Schwarz (2014) have more recently set the tone for renewing the importance of understanding human cognition by studying how we are affected by our bodily feelings and how we interact with others through our senses. Different theoretical perspectives may actually be beneficial not just to challenge or further understand well-established theories of embodied cognition in consumer research but also to complement the understanding of already observed effects under conditions not yet investigated. This dissertation builds upon this new wave of embodied cognition research and provides two studies that use an interdisciplinary approach to explore the impact of internal bodily feelings on subjective perception of presence and body ownership during virtual reality experiences.

1.1. Embodied Cognition in Consumer Behavior Research

Embodied cognition is the theory that simply states that cognition is also in the body (Wilson & Golonka, 2013). Its defining notions, however, span from more conservative ideas, which see the states of body only as another factor influencing and biasing cognition (Eerland et al., 2011), to more radical ideas in which cognition is no longer formed by the brain only but by a holistic body-brain system (Wilson & Golonka, 2013). The theory gained its relevance in the early 1990's when new theories of memory emerged as an alternative to the "modal view" (i.e., the traditional view of memory according to aspects such as short and long-term, and semantic and episodic) used in consumer behavior research, providing for the first time a focus on mental representations, perceptual aspects of cognition, and on the contextual flexibility necessary to take into consideration both rational and irrational aspects of human behavior (Malter, 1996). This new perspective in consumer behavior research also followed the lead of emerging theories in other cognitive sciences such as the somatic marker hypothesis (Damasio, 1994), which brought attention back to the role of emotions and bodily feelings in decision-making.

A new wave of studies in consumer behavior emerged based on this new view and focused on challenging the dominant paradigm by investigating the effect of exposure to sensorial stimuli in decision-making and judgment that could not be taken into account by the traditional models (Krishna & Schwarz, 2014). The current body of research has provided evidence of the importance of embodied cognition in influencing consumer perception in different aspects such as the relationship between physical temperature and social experiences (Zhong & Leonardelli, 2008; Williams & Bargh, 2008), motor fluency and product preference (Elder & Krishna, 2011; Eelen, Dewitte, & Warlop, 2013), muscle contraction and willpower augmentation (Hung & Labroo, 2010), and other diverse experiments involving the impact of different sensorial stimuli on behavior, perception, and judgment (for an earlier review see Krishna, 2012; but also see Krishna & Schwarz, 2014 for a later review).

By accepting the existence of complex relationships between bodily feelings, emotion, cognition, and behavior, consumer behavior researchers are also starting to recognize the need to learn and apply methods from other disciplines in order to go beyond the identification of effects and move towards a deeper understanding of the processes behind them, some of which are focused on analyzing neural and physiological responses corresponding to the consumers' bodily states when those are performing different tasks and under different conditions (Preston, 2011; Krishna & Schwarz, 2014).

Within this new context, interest in a deeper exploration of VR experiences emerged, pushing consumer researchers to further explore how sensations from the body generate our feelings and have an impact on our perception (Barret & Simons, 2015). Unique in comparison to other media, VR experiences create illusions induced by rich and interactive stimuli that are similar to real experiences (Riva et al., 2016), inducing feelings and driving hedonic consumption in order to enhance product-related experiences (Ben-Ur, Mai & Yang, 2015). VR is, thus, seen as a unique communication tool that can be more powerful than memory or imagination, more controlled, and as effective as real experiences in inducing emotional responses (Riva et al., 2016).

This closer relationship between neuroscience and consumer behavior research is considered by some as an opportunity to provide new empirical findings, deepen the theoretical development of the field, and broaden the audience by allowing consumer researchers to provide both psychological and physiological explanations to diverse phenomena under different contexts (Yoon et al., 2012). However, when the topic of investigation is consumer experiences within virtual environments, interdisciplinarity seems to become even more relevant, as it involves understanding VR as an experience in which the consumers' subjective perception of the virtual environment (including their emotional, cognitive, and behavioral responses) are taken into consideration (Steuer, 1992). Thus, the following section describes two core aspects of VR experience (i.e., the senses of presence and body ownership), followed by a literature review on the importance of bodily feelings on the experience of VR.

1.2 Virtual Reality Experience

Virtual Reality is considered to be the "ultimate communication medium" since it has the unique ability to create the illusion that the virtual experience is in fact real (Riva et al., 2016). VR has the capacity to drive hedonic consumption via behavioral outcomes (e.g., influence shopping behavior by inducing feelings of accomplishment), enhance product-related experiences (i.e., the dynamic interaction between consumers and products), and induce emotional feelings (i.e., pleasure) at both social and individual levels (Ben-Ur, Mai, & Yang, 2015). Altogether, these capabilities make VR one of the most promising technologies in the world, attracting the attention of both academics and managers due to its potential to generate new and creative forms of interactive experiences between brands and consumers.

The definition of the term "Virtual Reality" is still under discussion and it varies according to the body of literature on which one is focused, with fields such as computer science paying more attention to the technological system used to create the experience, while human-oriented fields such as psychology and neuroscience being focused on the subjective experience of the interaction between human and computer-generated environment (Riva et al., 2016).

Steuer (1992), however, suggests that defining VR by means of the technology (i.e., hardware) is inadequate for different reasons, including the fact that it does not allow for a clear comparison between those systems categorized as VR since the technology by itself does not provide a conceptual unity of analysis for VR. To solve this issue, Steuer (1992, p. 76-77) focused on the experiential aspect of VR to define it as "a real or simulated environment in which a perceiver experiences telepresence". Steuer's (1992) definition of VR does not need to take into account a particular device and has as its key component the sense of presence, which he called telepresence to refer to the mediated (by a communication medium) experience of presence. Such definition of VR shifts the scope of presence from the mere technological aspects to focus on the subjective experience of being in a mediated environment, thus enabling the distinction between VR and other similar technologies such as augmented reality (AR), which is focused on integrating virtual objects with the real environment in real time so that they appear to coexist within the real world (Azuma, 1997).

Nevertheless, research on VR experiences has also shown that the sense of presence in virtual worlds seems to be intrinsically related to the power of taking meaningful actions and interacting with the virtual world by "experiencing agency" (Herrera, Jordan & Vera, 2006). Thus, by enabling the manipulation of and interaction with elements, agency requires one to be able to locate the cause of altered inputs in one's body rather than in the world (Russel, 1996), suggesting the importance of exploring both the senses of spatial presence and body ownership when it comes to assessment of VR experiences (Tang, Biocca & Lim, 2004).

1.2.1 Presence

VR and presence are closely related concepts. Earlier definitions of VR such as the one provided by Steuer (1992) already highlighted the importance of presence in defining VR as an experience. Biocca (1992, p.5-6), suggests a similar definition also focusing on the concept of presence, stating that VR can be defined as "*an environment created by a computer or other media, an environment in which the user feels present"*. Thus, Steuer's (1992, p.76) definition differs from others due to the usage of the term "telepresence" (i.e., *the experience of presence in an environment by means of a communication medium*) instead of presence. Lombard and Jones (2015), however, point out that telepresence is only one of the different terms derived from presence, with other terms being used according to the phenomenon studied. In their review paper, Lombard and Jones (2015) point out different terms briefly described below:

- Spatial presence: The most common type of presence and the one in which telepresence and presence are usually mixed. It comprises the feeling, sense, or state of "being there" in a space or environment. Here, the term telepresence comes as an attempt to define this feeling of presence in a mediated environment, but it is still used interchangeably with presence depending on the context.

- Social presence: Term used to define presence related to social entities as "*the experience or sense of being with another,*" either humans or not (Biocca, Harms & Burgoon, 2003). Here, diverse dimensions are mentioned such as perception of salience of others, perceived co-location, mutual understanding, psychological closeness, and affective and behavioral engagement. Interestingly, these dimensions seem to converge with the concepts of "theory of mind" and empathy, which, according to Singer et al. (2004), are suggested to be the two most essential aspects in determining the success of social interaction and understanding. "Theory of mind" is categorized as the cognitive route to social understanding, and is defined as "*the ability to understanding others' mental and affective states by means of reasoning about the thoughts, emotions or beliefs of others*" (Winter et al., 2017, p. 1). Empathy, in turn, is the affective route to social understanding, and is defined by Engen and Singer (2013, p. 275) "*as the process by which an individual infers the affective state of another by generating an isomorphic affective state in the self, while retaining knowledge that the cause of the affective state is the other*".

- Engagement: Term that comprises the connection with the content presented and is closely related to concepts such as attention, involvement, immersion, flow, and absorption.

- Realism: This concept basically refers to the perceived correspondence between a technology-mediated experience and a non-mediated experience. It can also be seen as the illusion that the experience is "real" (Riva, 1998).

- Cultural presence: This term refers to the idea that reality (and realism) is socially and culturally constructed, therefore, presence should always be used by taking cultural and social factors into consideration.

- Parapresence: A concept related to the "*perception that a person or entity is physically present in one's environment when they are not, and could not logically be, present*" Lombard and Jones (2015, p.26).

- Self-presence: A concept defined by Ratan (2012, p. 325) as *"the extent to which some aspects of a person's proto (body-schema) self, core (emotion-driven) self, and/or extended (identity-relevant) self is relevant during media use"*. Observe that with this concept it is possible to identify how the idea of presence is mixed with emotional and bodily feelings.

Lombard and Jones (2015) suggest that the diverse terms that derive from presence are not just a signal of the conceptual confusion of a relatively young and fast-evolving field but also a reflection of the richness of aspects (cognitive, affective, and perceptual) that involve the term. Riva et al. (2016) add to the discussion by stating that there is no current general consensus about the definition of presence. However, as the field evolves, researchers are starting to agree that presence is a multi-faceted construct and that single constructs such as technological immersion, emotional engagement, absorption, and attention cannot by themselves fully explain what presence is, although all of them do have a potential role in the understanding of presence.

Thus, more recent concepts such as self-presence, which derives from neuroscientific theories such as the idea of self from Damasio (1999), are starting to signal the importance of embodied aspects within human experience and tending to become increasingly relevant as the technology evolves. Moreover, Ratan's (2012) idea of self-presence also relates to the idea of the subjective experience of body ownership (i.e., perceiving that a body is my body, even when knowing that the body is not mine or not real). Ratan (2012, p. 325) states that "*just as the experience of presence involves engaging with a virtual environment as if it were a physical environment, the experience of self-presence involves using a virtual self-representation as if it were integrated with the physical self*".

These more recent views of presence and body ownership reflect how intertwined the concepts are, thus leading us to adopt in this research the assessment of VR experience through the evaluation of both constructs. In order to facilitate the measurement of presence and body ownership, we decided to assess the constructs separately by adopting the Witmer and Singer (1998, p. 225) classical view of presence as the "*subjective experience of being in one place or environment, even when one is physically situated in another*" and by adopting body ownership as the sense that a body (or part of it) is *mine* (Liang et al., 2015; Gallagher, 2000). The decision was made in order to minimize problems with the validity of the measurement by using the well-established Witmer & Singer scale of presence (1998) as well as the previously-used body ownership scale based on Suzuki et al. (2013) and Aspell et al. (2013). Thus, due to its relevance, the concept of body ownership is described in greater depth in the section below.

1.2.2 Body Ownership

Body ownership (just like presence) is considered to be a "feeling" or a "sense", but its subjective experience is related to the sense that a body (or part of it) is *mine* (Liang et al., 2015; Gallagher, 2000). This sensation can be related to another body or body part, either real or virtual, leading to the perception that the other body is your own body. Thus, body ownership illusions can make bodily sensations in the other body seem unique to oneself, even when the person knows the body is not real (Bergström, Kilteni & Slater, 2016).

Thus, body ownership can be seen as a type of presence in which the feeling is not in relation to the surroundings or the environment but towards the ability of being inside, having, and controlling a physical or virtual body (Kilteni, Groten & Slater, 2012). In fact, Riva et al. (2016) suggest that VR can be defined as an embodied technology because the user's experience is induced by presenting them both with a virtual world and a virtual body, which reinforces the importance of investigating both the senses of presence and body ownership when assessing VR experiences.

Body ownership and illusions of body ownership are aspects of great importance in the study of Bodily Self-Consciousness (BSC) once they focus on the representation and modified representation of one's body (Maselli & Slater, 2013). In fact, Blanke (2012), considers that body ownership experience is one of the three most important aspects of BSC, along with self-location (i.e., "where I am in space" – resembling the classical idea of presence) and first-person perspective (i.e., "from where I perceive the world"). Therefore, bodily self-consciousness feelings are currently considered as an integrated and complex interplay of a diverse range of factors, including proprioceptive (i.e., sensation of where the body is located in space), vestibular, and multisensorial information from both outside (e.g., exteroceptive) and inside (e.g., interoceptive) the body (Riva et al., 2016; Tsakiris, 2017; Maselli & Slater, 2013).

Despite the importance of body ownership illusions in VR experiences, most of the current effort made in VR is focused on the development of external stimulation, mainly audiovisual, with more advanced technologies also generating tactile feedback. Very little has been done up until now to explore how internal bodily sensations can influence VR experiences. But as scientific evidence accumulates, and theoretical knowledge advances, efforts to enhance VR experiences will potentially come from the simulation of the internal body. Moreover, using VR experiences for the simulation of internal sensations can lead to new transformative experiences for both clinical and non-clinical subjects to improve well-being through a better understanding and controlling of emotional and bodily responses (Riva et al., 2016). Thus, due to the increasing importance of interoception and embodied aspects in VR experiences, we briefly describe in the next section the current state of research on interoception and how it relates to VR.

1.2.3 The Role of Internal Bodily Feelings on VR Experience

The idea that bodily sensations are linked to our emotions, perceptions, and behaviors is not new and draws back to the Jamesian theory of emotions (James, 1984), which states that emotions emerge from the perception of bodily changes. Schachter and Singer (1962), however, state that emotional experiences caused by physiological arousal would be dependent on contextual factors or cognitive appraisal, that is, feelings would be an interpretation of the physiological changes. More recently, this relation between emotion, bodily changes, and decision-making became more popular with Damasio's (1994) work on the Somatic Marker Hypothesis, which suggests that decision-making could be influenced by emotional markers that would arise from the body. Although the theoretical framework of these ideas is still under debate (see Dunn, Dalgleish, & Lawrence, 2006), there is a consensus among researchers that emotions are psychological states that involve behavioral, experiential, and visceral changes (Seth, 2013).

Bodily feelings have been investigated in different contexts, with previous studies providing evidence of their relationship with the activation of brain regions (especially the anterior insular cortex and the anterior cingulate cortex) during sensations such as thirst (Denton et al., 1999), pain (Kong et al., 2006), sensual touch (Olausson et al., 2002), warmth (Olausson et al., 2005), coolness (Craig, Chen, Bandy, & Reiman, 2000), cardiac awareness (Garfinkel et al., 2015), and body ownership (Tsakiris, Tajadura-Jiménez, & Constantine, 2011; Suzuki et al., 2013; Aspell et al., 2013; Crucianelli et al., 2013; van Stralen et al., 2014).

The ability to sense physiological conditions of the body is crucial to achieve optimal solutions (i.e., reduce error prediction) since it enables the generation of well-adapted feelings by integrating the ascending sensorial activity of the body in the forebrain (Craig, 2015). Several of the contemporary views on interoception also suggest a crucial role for the insular cortex in processing the ascendant internal bodily signals associated with emotional states (Craig, 2009; Critchley & Seth, 2012; Seth, 2013; Gu, et al., 2013), which relies on early indications that this region contains a viscerotopic map of the body (Cechetto & Saper, 1987). In a general sense, bodily signals from primary afferents travel through a lamina-I spinal-thalamo-cortical pathway that leads to the insula to form our emotional experiences (for a detailed neuroanatomical explanation see Craig, 2009). Bodily signals also play a role in the generation of a multisensory map of the body, synchronizing our sensorial experiences with our interoceptive predictions (Barret & Simons, 2015).

Interoceptive feelings, however, are not equally perceived by everyone, and this perceptual variation has been interchangeably called interoceptive sensibility, sensitivity, accuracy, or awareness. However, previous studies pointed out that the methods used to investigate these feelings go from self-report measurements to cardiac activity tasks, and that they do not measure the same thing (Garfinkel & Critchely, 2013; Garfinkel et al., 2015). Thus, in an effort to clearly define each facet, Garfinkel et al. (2015) suggested a differentiation between the terms according to the following:

- Interoceptive accuracy: The objective accuracy in detecting bodily changes, assessed by comparing one's ability to detect his or her own cardiac activity beat-by-beat with the actual cardiac activity using an electrocardiogram.

- Interoceptive sensibility: The subjective tendency to feel and believe in one's perception of bodily sensations, assessed via self-reported measures.

- Interoceptive awareness: The metacognitive awareness of interoceptive accuracy, defined as the extent to which the confidence in one's perceived heartbeat count can predict his or her own actual performance. According to Garfinkel & Critchely (2013), this level is the least studied in the literature and can be calculated by measuring the relationship between accuracy and sensibility (e.g., via correlation or area under the ROC curves).

Although interoception has gained importance in the study of body ownership, few studies have provided evidence of the relationship between interoceptive feelings and subjective experiences of body ownership, and even fewer during VR experience. Tsakiris, Tajadura-Jiménez, & Constantine (2011) provided early evidence (via median split analysis) that lower body-awareness increases the tendency to experience body ownership illusions, thus providing evidence of an inverse relationship between accuracy via tracking task and body ownership. Other researchers used slow affective touch during a classic rubber hand illusion task (Crucianelli, et al., 2013; van Stralen et al., 2014) to demonstrate how affective touch can enhance body ownership illusion. However, only two studies, one conducted by Suzuki et al. (2013) and another conducted by Aspell et al. (2013) used Virtual Reality to investigate the impact of interoceptive signals on body-ownership. But while both studies provide evidence that body ownership can be enhanced by real-time cardio feedback synchronous with the participants' actual heartbeat, only Aspell et al. (2013) provide evidence of a full-body illusion, with Suzuki et al. (2013) providing evidence of virtual hand ownership. It is important to note that none of these studies explored the three-levels of interoception, with interoception being mostly assessed via the accuracy level.

The evidence from these studies suggests an impact of internal bodily feelings on VR experience, leading to the creation of new theories and technologies that can advance the understanding of VR experience. Riva et al. (2016), for example, proposed a new concept called "Sonoception" in which a technological device that can be used during VR experiences would integrate multisensorial bodily inputs (interoceptive, proprioceptive, and vestibular) by emitting sound and vibration in muscles, stomach area, chest, and head. This device attempts to optimize the sense of presence and body ownership by stimulating or simulating the contents of the inner body and is the first to try to tap into the integration of interoceptive and exteroceptive signals to enhance VR experiences, pushing towards a new wave of VR technologies and experiences.

Despite the increasing relevance of the topic, it is still possible to identify a gap in both consumer behavior and psychology literature in which there is a lack of understanding of how Virtual Reality experience by means of presence and body ownership can be associated with the three levels of interoception (i.e., accuracy, sensibility, and awareness – with awareness being so far almost completely unexplored). More importantly, conceptual differences pointed out by Garfinkel et al. (2015) also reflect variations in the outcome values of the same levels of interoception when different methods are used.

Interoceptive accuracy, for example, has two established measures: the heartbeat tracking task (Schandry, 1981; and Hart et al., 2013), which assesses accuracy by asking people to attend and silently count their heartbeats; and the heartbeat detection or discrimination task (Brener & Jones, 1974; Whitehead et al., 1977), which uses external stimuli (tones or lights, or tactile stimuli) to ask participants if the stimuli are in sync or not with their own heartbeats.

Both methods are well established. However, the tracking task has been criticized for its lack of reliability caused by the influence of expectancies, time estimation, and different attentional aspects (Ring et al., 2015; Windmann et al., 1999). Moreover, the tracking and detection tasks involve two different attentional processes (Forkmann et al., 2016): focusing on visceral sensations and keep tracking of their count (for the tracking task) and focusing on visceral sensations while noticing external signals to compare or discriminate their synchronization (for the detection task). The differences between the methods also seem to have an impact on the relationship between the levels (Schaefer et al., 2012; Hart et al., 2013; Forkmann et al., 2016), reinforcing the importance of further exploring this methodological aspect.

The conflicting results and conceptual disagreements in the field highlight the need for further conceptual and methodological exploration of the three-level model as well as its association with other constructs. Thus, the findings that come from further exploration of the topic have the potential to consolidate the conceptual and methodological bases of the field and enable practical insights that might lead to the next generation of VR technologies (Tsakiris, 2017; Riva et al. 2016).

Therefore, considering the proposed divergence between the three levels of interoception and its methodological variations (Garfinkel et al., 2015; Meessen et al., 2016; Forkmann et al., 2016), as well as the initial evidence of the association between interoception and presence (Seth, Suzuki, & Critchley, 2012), body ownership (Tsakiris, Tajadura-Jiménez & Costantini, 2011; Suzuki, et al., 2013; Aspell et al., 2013), and decision-making (Kirk, Downar, & Montague, 2011; Werner et al., 2013), we further investigate how this relationship might be influenced by the methodological aspects that involve the calculation of interoception as well as by the type of VR experience selected.

Chapter 2: Exploring the Impact of Interoception on Virtual Reality Experience

To start our exploration on how interoceptive abilities might be associated with the two core aspects of Virtual Reality (VR) experience (i.e., perception of presence and body ownership), we decided to first investigate Garfinkel's (2015) three-level model of interoception using the heartbeat tracking task, considered the most accessible and popular method to calculate interoception (Kleckner et al., 2015). In this chapter we detail our first study, in which we collected data from 49 (valid) healthy participants who played two VR games. An experiential-oriented VR game in which the participants were free to interact with the virtual world without the need to perform any task, and a decision-making VR game in which participants were required to perform a visual-spatial task under time-pressure.

Study 1 provides, for the first time, evidence of a positive correlation between awareness and presence, as well as between awareness and body ownership (EBO). Interestingly, this correlation was only revealed when participants played the experiential game. No correlation was found between any of the levels of interoception and the senses of presence, or EBO during the decision-making game, nor did we find any significant correlation between decision-making performance and interoception during the decision-making task. Findings from Study 1 reinforce the importance of exploring the level of awareness instead of focusing on accuracy only, as has been mostly done so far in previous research (Owens et al., 2018). Our findings suggest that awareness, by taking into consideration the extent to which one's confidence predicts his or her interoceptive accuracy, can more precisely infer how interoceptive feelings impact on consumers' sense of presence and EBO during a VR experience.

The limitations in our study raised questions that will be addressed in Study 2. Yet, this is the first study (to the extent of our current knowledge) to explore the association between the three-level model of interoception, presence, and body ownership, thus, shedding light on important conceptual and methodological aspects that can advance consumer behavior research knowledge on how we perceive and experience reality mediated by VR technologies.

2.1 Introduction to Study 1

Conceptual and methodological aspects regarding the topic of presence, embodiement, and especially interoception, are still under constant debate (Lombard & Jones, 2015; Garfinkel et al., 2015; Ring et al., 2015). In the current body of literature only one study (Tsakiris, Tajadura-Jiménez, & Constantine, 2011) has investigated the association between interoceptive accuracy (via tracking task) and body ownership (i.e., the sense or feeling that a body or part of it is mine even when knowing that the body is not real), showing that people with low accuracy experience stronger experiences of body ownership. The authors suggest that a strong sense of interoception grounds one in his/her sense of self, therefore, making it more difficult to experience body ownership illusions. However, Suzuki, et al., 2013 and Aspell et al., 2013 provided somewhat contrary evidence, by showing that body ownership illusions can actually be enhanced by providing real-time interoceptive feedback (i.e., cardio-visual signals) synchronous with the actual heartbeat of the participants. However, of these two latter studies, only Suzuki et al., (2013) investigated the association between accuracy (via detection task) and body ownership, suggesting a positive correlation between accuracy and body ownership.

Thus, because of the differences in the methods of calculating interoception used by Suzuki et al. (2013) and Tsakiris, Tajadura-Jiménez, & Constantine (2011), it is difficult to conclude whether body ownership indeed correlates with interoceptive accuracy and what is the direction of the correlation. Moreover, to our current knowledge, no study has yet explored the association between the interoceptive levels and the sense of presence (i.e., the sense or feeling of "being there" in a space or environment).

In fact, the current body of literature about interoception is mainly focused only on the first two levels of Garfinkel and Critchley's (2013) model (i.e., sensibility and accuracy). As far as we know, no study has provided evidence of the impact of interoceptive awareness on either body ownership or presence or subjective experience of body ownership in virtual reality experiences.

In addition to the current lack of studies about the relationship between awareness and other important variables for VR experience, the current body of research also agrees on the limitations of interoceptive accuracy which can be influenced by expectancies, guesses, and low validity (Ring et al., 2015; Kleckner et al., 2015). These aspects, however, are supposedly balanced in the calculation of interoceptive awareness since they are taken into consideration to "*quantify one's explicit knowledge of (and confidence in) their interoceptive accuracy*" (Garfinkel & Critchley, 2013, p. 233).

By taking these previous studies into consideration, we designed Study 1 with the objective of further understanding how the three different interoceptive levels, when calculated via the most accessible method currently in use (i.e., tracking task), are associated with the senses of presence and body ownership. Moreover, because we use the tracking task, we followed Tsakiris, Tajadura-Jiménez, & Constantine (2011) to hypothesize the negative direction of the relationship between interoception and both the senses of body ownership and presence. Thus, H1 goes as:

H1: There is a negative correlation between (a) interoception and presence and between (b) interoception and body ownership.

It is important to highlight that even if no previous study has investigated the relationship between interoception and the presence sensation, we draw from previous research on VR experiences that has shown that the sense of presence in virtual worlds seems to be intrinsically related to the experience of agency (Herrera, Jordan & Vera, 2006), which in itself requires one to be able to locate the cause of altered inputs in one's body rather than in the world (Russel, 1996), suggesting the association between spatial presence and body ownership VR experiences (Tang, Biocca & Lim, 2004).

Although interoception is linked to emotions and the perception of self (Craig, 2015), the ability to sense bodily signals also plays an important role in both decision-making and motivated behavior via homeostatic (i.e., internal control via autonomic responses that interact to maintain optimal use of energy in the body) and allostatic (i.e., the dynamic process of achieving or returning to homeostasis via behavioral actions or physiological adaptations) processes.

Empirical studies have turned to the impact of interoception in decision-making, showing how variations in perceiving bodily changes can affect choice selection. In one of these studies, Werner et al. (2013) showed that subjects with high (versus low) interoceptive accuracy (measured in terms of heartbeat perception) demonstrate superior performance in the Iowa Gambling Task (IGT), a task in which participants are asked to choose a card (over different trials) among four different decks of cards, with the decks differing in terms of potential immediate and future wins and losses. The task was developed by Bechara et al. (1994) to demonstrate how bodily signals emerging from an emotional reaction to the stimuli (i.e., somatic markers) can bias choice selection before conscious awareness of the rules of the task takes place. These results were consistent with Dunn et al.'s (2010) study, which demonstrated that higher electrodermal activity was able to better predict when subjects with accurate interoception (vs. poor accuracy) would reject rather than accept offers during a decision-making task called the Ultimatum Game. In this task the rejection of offers is related to the perception of unfairness but it also entails a failure in emotional regulation. This interaction between behavior and physiological signal seems to support the role of interoception in regulating bodily signals associated with emotional experiences to lead to more advantageous decisions. Thus, the study provides two important insights: First, that higher interoceptive accuracy seems to enhance the perception of disadvantageous and unfair choices; and second, that bodily signals can arise from different mechanisms beyond cardiac activity.

Two aspects are then of greater relevance for us: 1) Previous evidence pointed towards a positive association between interoception and better outcomes in both emotional regulation and intuitive decision-making (Kirk, Downar, & Montague, 2011; Dunn et al. 2010; Dunn et al., 2012; Werner et al., 2013); and 2) VR games, which can be either performance-oriented (i.e., when the player has to perform under a certain type of pressure) or experiential-oriented (i.e., free interaction with no pressure to perform). Together, these points led us to draw our second hypothesis, which is focused on exploring the association between interoception and decision-making performance in VR.

H2: There is a positive correlation between interoception and decision-making performance in performance-oriented VR games.

2.2 Method

2.2.1 Experimental Design and Procedure

To investigate the hypotheses, a single-factor within-subject experimental design was created. Two conditions in the form of two different games (see appendix B for screenshots of the games) were used during the experiment and called “Experiential” (EXP) and “Decision-Making” (DM). The conditions were chosen based on previous findings linking interoception to experiences of body ownership (Suzuki, et al., 2013; Aspel et al., 2013) and to decision-making and emotional regulation (Kirk, Downar, & Montague, 2011; Werner et al., 2013; Sütterlin et al., 2013). All participants went through both conditions, and the order of the conditions was randomized. Finally, before playing each game, participants went through a training session in which they received instructions on how to play the game and use the controllers.

The Experiential (EXP) condition was designed for participants to focus merely on interacting with the virtual environment, without them feeling any pressure to perform any specific task. For this condition, we selected a VR game called “London Heist” (SIE London Studio, UK), an action/thriller first-person-perspective game in which the gamer is part of a gangster world in London, UK. Although the game has tasks to perform, all participants were only allowed to play the first 10 minutes of the game, during which the participant was free to explore the virtual environment (e.g., grab a mobile phone or smoke a virtual cigar) and participate in the game’s story without having to perform any specific task. We also believe that 10 minutes was enough time to allow them to have an immersive experience without high risks of motion sickness.

The “Decision-Making” (DM) condition was designed to focus on participants’ ability to perform visual-spatial decision-making tasks under time pressure. The game selected, called “SuperHyperCube” (Kokorami Collective), is a “Tetris-like” spatial reasoning puzzle game in which the player’s perspective is fixed from behind a 3D geometrical shape, requiring the user to tilt his or her head to see around the edges of the shape and rotate the shape to match it to a rapidly approaching target gap. The game becomes more difficult as the player’s score increases and it provides the participant with approximately seven seconds to take a decision before the 3D form reaches the target gap. The game also provided the possibility for the player to speed up his or her decision whenever they believed to have found the right match between the form and target gap; this provided them with a reward in terms of a bonus score, but also increased the risk of losing due to the greater distance between the form and the target gap. Combined, the features of the game provide a good trade-off between reward and response time that puts to the test the participants' emotional self-regulation ability.

Participants were greeted in the lab waiting room, where they were instructed to carefully read and sign the informed consent form in order to participate in the study. They were asked to fill out an initial online questionnaire before the experiment with the intent of collecting demographic data (i.e., age, biological sex, height and weight to calculate their Body Mass Index). Participants were informed about the experimental procedure by researcher and then asked to sit comfortably for 1 minute while their Resting Heart Rate was measured using a GO2 finger clip oximeter (Respironics Inc., PA, USA), placed on the participant's left index finger. After the Resting Heart Rate measurement, participants were then fitted with ECG electrodes and asked to complete a heartbeat tracking task (to measure interoceptive accuracy), followed by a confidence judgment task of each trial of heartbeat count (to assess interoceptive sensibility). Each participant performed the heartbeat tracking and judgment task six times and a Pearson correlation score was calculated to serve as an interoceptive awareness score (see Section 2.4. for details). The ECG signal was verified in real-time, with electrode adjustment and replacement being done in case of extreme noisy data due to greater body mass (i.e., situations in which R-waves and noise were not possible to differentiate from each other). The ECG equipment was used only to collect data during the heartbeat tracking task. During these moments, participants were resting in a still position, thus, avoiding movement noise in the data. After the heartbeat tracking task, the participants were asked to perform a time counting task that followed the same structure as the accuracy task, but required participants to count time in seconds instead of their heartbeats. Finally, the researchers instructed the participants on wearing the VR headset and how to play the games. All participants received instructions on how to play each game and were also asked to play a tutorial phase to learn the basic commands of each game. After each game, the participants were asked to fill out the presence scale (Witmer and Singer, 1998) and a body ownership scale based on Suzuki et al. (2013) (see Appendix A).

2.2.2 Participants

In total, we selected 49 healthy participants (26 male [53.06%]; mean age = 23.85, SD = 7.01, range = 18-45). Of the total number of participants selected, 17 were undergrads and the others were graduate students and/or professionals. All of them were recruited via our institution research panel. The study took around 1 hour and 30 minutes to be completed and we gave a gift card worth $30 to all participants after the completion of the experiment as compensation. The research was approved by the school's ethics committee and all participants signed a consent form before the start of the experiment.

2.2.3 Experimental setup

Participants sat facing a 50-inch TV at distance of 3 feet (0.91 meters). The chair was fastened to the floor to avoid extreme movement and to ensure participants` safety in the event of an intense movement during the main experiment. To create the immersive virtual reality experience, we used a PlayStation™ VR system console along with AKG K77 Pro Audio headphones to induce an immersive sound experience and two PS4 movement detection controllers to simulate touch and movement experiences. A feed-forward PS4 camera was mounted above the TV and aligned with the participants' face in order to provide the exact location of the participant and assure a correct visual angle.

For the chosen interoceptive accuracy measurement (i.e., heartbeat tracking task), an ECG signal was monitored using a BITalino's ECG system (Plux Inc., Lisbon, Portugal) and three Ag-AgCl electrodes. The system's sampling rate was 100Hz, bandwidth of 0.5-40 Hz, signal resolution of 10 bits, and voltage range of ± 1.5mV. The positive electrode was placed under the right clavicula and the negative electrode at the lower left lateral chest approximately under the left musculus pectoralis major and reference electrode under the left clavicula (Němcová et al., 2016). A finger clip GO2 Oximeter (Respironics Inc., PA, USA), placed on participant's left index finger, was also used to measure participants' Resting Heart Rate before we performed the interoceptive task.

2.2.4 Measures

To measure interoceptive accuracy we used the Schandry heartbeat tracking task (Schandry, 1981), which has been widely used in previous research as it is relatively easy to perform and is of relatively short duration (Kleckner et al., 2016). During this task participants were given the following instructions: "Please, count silently each heartbeat you feel in your body from the time you hear "start" to when you hear "stop" without manually checking your pulse". Task instructions were given by the researcher, who was constantly observing the participant through a one-way mirror and through a live video feedback input from a camera system placed in the experimental room.

The task was repeated six times (trials) using different randomized durations (25, 30, 35, 40, 45, 50 seconds). During each period, the ECG system was recorded in order to calculate the accuracy score after each trial according to Hart et al. (2013), using the following transformation:

{1 – (|Nbeatsreal - Nbeatsreported|)} / {(|Nbeatsreal + Nbeatsreported|)/2}, where:

- *Nbeatsreal*: the number of heartbeats objectively captured by the ECG;
- *Nbeatsreported*: the number of heartbeats perceived by the participant.

An average was computed from the six trials scores resulting on a final accuracy score ranging from -1 to +1. A score between 0 and 1 indicates moderate differences between actual and perceived heartbeats while a score between -1 and 0 indicates extreme differences between perceived and actual heartbeats (Forkmann et al., 2016).

In order to assess interoceptive sensibility, we asked participants after each accuracy trial to indicate how confident they were that their heartbeat estimation was correct. Confidence judgment was made by using an online visual continuous scale from 0 to 10 using an iPad with its left extremity marked as "Total guess/no heartbeat awareness" and the right extremity labeled "Complete confidence/full perception of heartbeat". Interoceptive sensibility was then calculated for each participant as the mean of the six confidence judgments (Garfinkel et al., 2015; Forkmann et al., 2016). No feedback was provided in terms of the participants' performance.

Because awareness attempts to measure the extent to which the participants' confidence in their perceived heartbeat count can predict their own actual performance, we decided to follow Garfinkel et al. (2015) and calculate the awareness score of each participant by calculating within-participant Pearson's correlation coefficients between confidence and performance score over the six trials.

2.2.5 Scales

The original presence scale published by Witmer and Singer (1998) is a 24-item (reverse items 14, 17, and 18) single factor continuous visual scale ranging from 0 to 7 with reported Cronbach's alpha of 0.88. The 19 initial questions form the *Presence* scale, which does not take into consideration sound and touch. The last five items, however, can be added to the scale if the VR experience uses sound (items 20 to 22) or allows the user to interact with virtual objects (items 23 and 24), forming the *Total Presence* factor (see Appendix A for full version of the scale). No Cronbach's alpha is provided for the 24-item scale in the Witmer and Singer (1998) study. Sound and Touch related questions were considered because participants experienced the Virtual Reality games using studio quality headphones and PS4 movement detection controllers to simulate touch.

The EBO scale is comprised of four questions with items one and three comprising the *ownership* factor, focused on assessing the subjective experience of body ownership; while items two and four comprised the *control* factor, which provided equivalent attentional demands without relating specifically to body ownership. *Total EBO* factor was calculated by summing up all the scores of all questions using unit (equal) weighting. All responses were collected using a 7-point continuous visual scale with - 3 representing "Strongly disagree" and + 3 "Strongly agree".

To assess the reliability, we conducted a series of exploratory factor analyses for both DM and EXP conditions. We choose to do the analysis per condition to ensure that there were no major changes in the consistency and structure of the scales for each condition. EFA analysis for the presence scale during both the EXP and DM condition failed to produce a satisfactory factor structure, with item-loading probably affected by the low subject-to-item ratio (2:1) (Costello & Osborne, 2005). A forced single factor EFA analysis was then conducted (see Table 1) to test the factor structure.

Table 1. Loading of the items retained after exploratory factor analysis – presence scale.

	EXP condition	DM condition
Presence_Q1	.440	.354
Presence_Q2	.394	.320
Presence_Q3	.604	.572
Presence_Q4	.663	.731
Presence_Q5	.761	.673
Presence_Q6	.613	.488
Presence_Q7	.648	.595
Presence_Q8	.429	.279
Presence_Q9	.391	.505
Presence_Q10	.548	.714
Presence_Q11	.618	.569
Presence_Q12	.562	.364
Presence_Q13	.764	.751
Presence_Q15	.565	.266
Presence_Q16	.690	.353
Presence_Q19	.312	.301
Presence_Q20_sound	.599	.444
Presence_Q21_sound	.662	.316
Presence_Q22_sound	.391	.237
Presence_Q23_haptics	.473	.382
Presence_Q24_haptics	.487	.354

Extraction Method: Principal Axis Factoring.

The total structure (i.e., total presence factor, with 24 items) was assessed first for the EXP condition (KMO = .611, Sphericity < .001, communalities above .416, item loading above .312). Three items were removed (18, 14, 17), due to their corrected item-total correlation below 0.2, leading to a final Cronbach's alpha of .896 (corrected-total item correlation > .524). We also assessed the reliability of the presence scale without the block of questions related to sound and touch, thus, allowing us to make an equivalent comparison of the experiences across different genres of VR games that may not be so focused on haptics or sound. When these questions (Q20 to 24) were removed, the final reliability test via Cronbach's alpha was of .878.

EFA and reliability tests for the presence and total presence scale during the DM condition followed a similar pattern (KMO = .474, Sphericity < .001, communalities above .420, item loading above .312), with items 14, 17, and 18 once again removed due to inter-item correlation below 0.2, leading to a final Cronbach's alpha of .832 (for total presence scale) and .816 (for presence scale without the sound and touch items; all corrected-total item correlation > .524).

EFA for the EBO scale during EXP condition supported Suzuki et al. (2013) 2-factor structure with items 1 and 3 (ownership subscale) loading in factor 1 (respective loads = .931, .362) while items 2 and 4 loaded in factor 2 (respective loads = .307, .648). Reliability test via Cronbach's alpha for the whole scale in the EXP condition was of .549 (corrected item-total correlation > .229). Cronbach's alpha for the ownership factor in the EXP condition was of .761 (corrected item-total correlation > .614).

The EFA for the EBO scale during the DM condition also supported the 2-factor structure (control vs ownership scale), with items 1 and 3 (ownership subscale) loading in factor 1 (respective loads = .907, .694) and items 2 and 4 (control subscale) loading in factor 2 (respective loads = .621, .824). Cronbach's alpha for the whole scale in the DM condition was of .675 (corrected Item-Total correlation > .366). Cronbach's alpha for the ownership factor in DM condition was of .761 (corrected item-total correlation > .614)..

2.3 Results

2.3.1 The Three-Level Model of Interoception

Following Forkmann et al. (2016) and Garfinkel et al. (2015), we started by conducting a correlation analysis to test if the multi-level conceptualization of interoception could be replicated. Results of the heartbeat tracking task showed no significant correlation between accuracy (M= .59, SD = .24) and sensibility (M= 4.59, SD = 2.03; r = .203, n = 49, p = .161), accuracy and awareness (M= .16, SD = .52; r = .046, n = 49, p = .753), and sensibility and awareness (r = -.087, n = 49, p = .553). To note, although awareness is the

Pearson correlation between accuracy and sensibility, the resulting Pearson score does not necessarily correlate with the variables that were used to generate it. Thus, the association represented by the correlation between accuracy and sensibility (i.e., awareness) may or may not be associated with each of its forming variables. Correlations were also calculated with z-score values and still provided the same results. Therefore, the results support the three-level model, suggesting that the interoceptive levels (calculated via the tracking task) are indeed assessing different dimensions as suggested by Forkmann et al. (2016) and Garfinkel et al. (2015).

Moreover, partial correlation when controlling for biological sex, age, and Body Mass index (BMI) did not reveal any significant correlation between the three levels. There were also no correlations between BMI, age, and any of the three levels individually. Only a negative correlation between accuracy and resting heart rate ($M = 72.65$, $SD = 11.68$; $r = -.309$, $p = .031$, $n = 49$) was found, which along with the correlation between interoceptive accuracy and time accuracy ($M = .72$, $SD = .19$, $n = 49$; $r = .523$, $p < .001$, $n = 49$) seem to support the evidence that accuracy via heartbeat tracking task is indeed influenced by one's ability to estimate time (Shah, Catmur, & Bird, 2017; Pollatos, Laubrock, & Wittman, 2014). Thus, by revealing the non-association between the three levels of interoception as stated by Forkmann et al. (2016) and Garfinkel et al. (2015), our initial results also provide support for us to further explore how each one of these levels may be associated with the senses of presence and body ownership.

2.3.2 Descriptive Statistics and Trend Analysis

Comparisons of means between both games (i.e., experiential-oriented game "EXP", visual-spatial matching-form game "DM") showed a higher average presence score for the EXP game (94.04 VS 93.35), with no statistically significant difference found between the means. A statistically significant difference was found only when the items relating to sound and touch were taken into consideration (i.e. Total Presence scale), with the EXP having again a greater mean than the DM ($M_{EXP-DM} = 9.826$, $F(1,95) = 7.482$, $p < .01$). The EXP condition also showed a higher mean score than the DM condition on the ownership scale, with the difference also being statistically significant ($M_{EXP-DM} = 2.259$, $F(1,96) = 72.461$, $p < .01$).

In order to verify a possible order effect such as fatigue or carry-over, we performed an analysis of variance at alpha .05 to compare the means of presence and ownership (for each condition) between the group who played the DM game first and the group who played the EXP game first. The analysis showed no significant difference in the order of conditions played, either for the presence score in the EXP condition ($M_{DMfirst-EXPfirst}$ = 5.481, F(1,46) = 1.503, p = .227) or in the DM condition ($M_{DMfirst-EXPfirst}$ = -1.679, F(1,47) = 0.180, p = .673). No significant order effect was found in terms of total presence scores, either in the EXP condition ($M_{DMfirst-EXPfirst}$ = 7.816, F(1,46) = 2.087, p = .155) or in the DM condition ($M_{DMfirst-EXPfirst}$ = 1.340, F(1,47) = .08, p = .778). However, the trend analysis for the ownership scores showed that the order of the conditions had a statistically significant effect for both the EXP ($M_{DMfirst-EXPfirst}$ = .638, F(1,47) = 4.557, p = .038) and the DM condition ($M_{DMfirst-EXPfirst}$ = 1.074, F(1,47) = 6.932, p = .011). Finally, no significant order effect was found in terms of performance scores, in the DM condition ($M_{DMfirst-EXPfirst}$ = 10.476, F(1,47) = 1.890, p = .176).

We believe that the observed order effect was caused by the importance of the first-person perspective (i.e., “from where I perceive the world”) in Bodily Self-Conciouness (Blanke, 2012). More specifically, because the DM did not provide the user with an avatar in first-person perspective as did the EXP condition, the participants experienced a contrast in ownership sensations. This was an expected limitation of our study, since we were unable to create our own VR experiences.

2.3.3 The Impact of Interoception on Presence (H1a)

To test Hypothesis 1a, which proposes that interoception and presence are negatively correlated, we conducted a series of correlation analyses between the three interoceptive levels and the factorial scores of presence (i.e., Q1 to 19) and total presence (Q1 to 24) for both the EXP and DM conditions. This initial correlation analysis (Table 2) provided no support for H1a, showing no significant correlation between the presence score (M = 78.88, SD = 14.75, n = 49) and accuracy or between the presence score and sensibility for either EXP or DM condition. However, the results showed a positive and significant correlation between the presence score (i.e., the first 19 items of the scale) and awareness (r = .377, p < .01) as well as between total presence and awareness (r = .412, p < .01), but only for the EXP condition.

Table 2. Correlation between interoception and Presence Score for EXP condition.

		Interoceptive Accuracy	Interoceptive Sensibility	Interoceptive Awareness	Presence Score	Total Presence Score
Interoceptive Accuracy	r	1				
	p					
	n	49				
Interoceptive Sensibility	r	.203	1			
	p	.161				
	n	49	49			
Interoceptive Awareness	r	.046	-.087	1		
	p	.753	.553			
	n	49	49	49		
Presence Score	r	.004	.068	.377**	1	
	p	.978	.644	.008		
	n	48	48	48	48	
Total Presence Score	r	-.029	.074	.412**	.977**	1
	p	.845	.619	.004	.000	
	n	48	48	48	48	48

To further test the relationship between awareness and presence, we ran a series of hierarchical regression analyses with awareness as the independent variable and presence as the dependent variable (Table 3). In the first pair of regressions (Model 1), awareness was set as the independent variable in the first block with its quadratic term set in the second block to test for threshold effect, (i.e., higher association between the variables in high versus low awareness due to a curvilinear relationship. Results showed awareness to be a significant predictor of presence (B = .377, p < .01), with a statistically significant linear model (Adj. R^2 = .123; F[1,46] = 7.600, p < .01). However, the increment of awareness squared not did result in a significant change, with the combined effect having a lower adjusted R^2 than the linear model (Adj. R^2 = .110; F[2,45] = 3.894, p = .028).

The next regression (Model 2) was designed with total presence as the dependent variable and awareness as the independent variable. The same procedure was followed here with awareness squared set in the second block in order to assess the possibility of a threshold effect. Results showed awareness to be a significant predictor of total presence (B = .412, p < .01), with a statistically significant linear model (Adj. R^2 = .151; F[1,46] = 9.386, p < .01). Once again, the increment of awareness squared did not result in a significant change with the combined effect showing a lower adjusted R^2 than the linear model (Adj. R^2 = .139; F[2,45] = 4.797, p = .013).

Table 3. Results of hierarchical regression analysis with presence and total presence.

Model		Blocks		Stand B	t	p	Adj. R^2	F	p
Presence Model I	X = Awareness	Block 1	Constant		36.968	<.01	.123	7.600	<.01
	Y = Presence		X	.377	2.757	<.01			
		Block 2	Constant		26.468	<.01	.110	3.894	.028
			X	.391	2.790	<.01			
			X^2	-.077	-.550	.585			
T. Presence Model II	X = Awareness	Block 1	Constant		40.703	<.01	.151	9.386	
	Y = T. Presence		X	.412	3.064	<.01			<.01
		Block 2	Constant		29.140	<.01	.139	4.797	.013
			X	.426	3.097	<.01			
			X^2	-.080	-.584	.562			

Thus, although the results of the correlation analysis between the presence and the three-level model showed no support to the hypothesis that there is a negative correlation between interoception and presence, we were able to reveal, for the first time, the existence of a significant positive correlation between awareness and presence. This interesting finding supports the importance of not just consolidating the conceptual aspects involving the topic, but also of investigating and comparing the association of each of the levels of interoception, further exploring the level of awareness instead of focusing only on accuracy and sensibility (Owens et al., 2018).

2.3.4 The Impact of Interoception on Body Ownership (H1b)

The correlation analysis between the three-level model and body ownership (Table 4) also provided no support for H1b, showing no significant correlation between interoceptive accuracy and total EBO score (M = 1.54, SD = 4.07, n = 48; r = .011, p = .942) and no correlation between interoceptive sensibility and total EBO score (r = .034, p = .819), both for the EXP condition. However, we again found a positive and significant correlation between interoceptive awareness and total EBO score ($r = .454$, $p < .001$) (Table 4).

Table 4. Correlation between interoception and Presence Score for EXP condition.

		Interoceptive Accuracy	Interoceptive Sensibility	Interoceptive Awareness	Ownership [(Q1+Q3)/2]	Control [(Q2+Q4)/2]	Total EBO
Interoceptive Accuracy	r	1					
	p						
	n	49					
Interoceptive Sensibility	r	.203	1				
	p	.161					
	n	49	49				
Interoceptive Awareness	r	.046	-.087	1			
	p	.753	.553				
	n	49	49	49			
Ownership [(Q1+Q3)/2]	r	.0.17	.216	.446**	1		
	p	.905	.137	.001			
	n	49	49	49	49		
Control [(Q2+Q4)/2]	r	-.003	-.072	.262	.108	1	
	p	.983	.622	.069	.458		
	n	49	49	49	49	49	
Total EBO	r	.011	.034	.454**	.637**	.835**	1
	p	.942	.819	.001	.000	.000	
	n	49	49	49	49	49	49

A t-test also showed the means of the ownership and control factors to be statistically different from each other ($M_{dif} = 2.14$, $SD_{dif} = 1.84$, $t(48) = 8.14$, $p < .001$), with a correlation analysis showing only a positive and significant correlation between the awareness and ownership factor ($r = .446$, $p < .001$, $n = 49$). Finally, the correlation analysis for the DM condition showed, once again, no significant correlation between any of the interoceptive facets and either the total EBO ($M = -3.47$, $SD = 1.90$, $n = 49$) or ownership factor ($M = -.751$, $SD = 1.50$).

To further test this relationship between awareness and EBO, we conducted another series of hierarchical regression analyses (Table 5). In the first pair (Model 3), ownership (i.e., the average score of Q1 and Q3) was set as the dependent variable and Awareness was set in block one as the independent variable, with its quadratic term set in block two in order to assess the possibility of a threshold effect. Results showed Awareness to be a significant predictor of ownership (B = .446, $p < .01$), with a statistically significant linear model (Adj. $R^2 = .182$; F[1,47] = 11.679, $p < .01$). However, the increment of Awareness Squared did not result in a significant change (R^2 Change = .004, F[1,45] = .219, p = .642), with its combined effect (Adj. $R^2 = .192$; F[2,45] = 6.582, $p < .01$) lower than the linear model.

Finally, in the second pair (Model 4), Total EBO was set as the dependent variable and Awareness was set in block one as the independent variable. EBO squared was set in block two. Results showed Awareness to be a significant predictor of EBO (B = .454, p = 0.01), with a statistically significant linear model (Adj. $R^2 = .189$; F[1,46] = 11.931, $p < 0.01$). However, the increment of Awareness Squared did not result in a significant change (R^2 Change = .020, F[1,45] = 1.185, p = .282), despite having its combined effect significant and with a higher adjusted R^2 than the linear model (Adj. $R^2 = .192$; F[2,45] = 6.582, $p < .01$).

Table 5. Results of hierarchical regression analysis with ownership and total EBO.

Model		Blocks		Stand B	t	p	Adj. R^2	F	p
Ownership Model III	X = Awareness	Block 1	Constant		8.626	<.01	.182	11.679	<.01
	Y = Ownership		X	.446	3.417	<.01			
		Block 2	Constant		5.791	<.01	.168	5.852	<.01
			X	.435	3.251	<.01			
			X^2	.063	.468	.642			
Total EBO Model IV	X = Awareness	Block 1	Constant		1.176	.084	.189	11.931	<.01
	Y = T. EBO		X	.454	3.454	<.01			
		Block 2	Constant		.491	.626	.192	6.582	<.01
			X	.427	3.202	<.01			
			X^2	.145	1.088	.282			

Similar to the analysis for H1a, the correlation analyses between the three levels of interoception and body ownership did not support the hypothesis of a negative correlation between interoception and body ownership, contrasting with the findings from Tsakiris, Tajadura-Jiménez and Costantini (2011). Moreover, our results once again pointed out the importance of investigating the level of awareness by revealing a significant positive correlation between awareness and body ownership. Interestingly, this correlation was only verified in the experiential condition - a result equivalent to the investigation of H1a - suggesting that the relationship between interoception, presence, and body ownership also depends on the type of VR experience presented to the user. This divergence between the conditions is further investigated in the next section.

2.3.5 The Impact of Interoception on Decision-Making Performance (H2)

To initially test H2, which suggests a possible positive correlation between interoception and performance in decision-making tasks, we ran a series of correlations between the three measurements of interoception and the scores obtained by the participants during the decision-making game. Average performance was obtained by calculating the mean score of four rounds of game play, thus reducing problems related to learning effects. Average total time playing the game was of 10min (SD = 3.2).

The initial results did not support H2, showing no significant correlation between accuracy and average performance (M = 57.90, SD = 26.85, n = 49), sensibility and average performance (r = 0.156, p = .285), or awareness and average performance (r = 0.084, p = .567). Descriptive analysis showed a progressive increase in the mean score per round, reaching a plateau on Round 3 and decreasing in round 4 (See Table 6).

Table 6. Descriptive analysis of the scores obtained during the decision-making task.

	N	Range	Min	Max	Mean	Std. Deviation	Variance
Round 1	49	206	6	212	46.86	37.82	1430.71
Round 2	49	198	5	203	63.20	43.62	1903.21
Round 3	49	181	8	189	63.47	46.86	2196.05
Round 4	49	226	9	235	57.82	44.90	2016.36
Average performance	49	117.3	19.5	136.8	57.90	26.86	721.75

Thus, because the difference in the scores could have been influenced by the learning process in playing the game itself, we decided to run a series of paired t-tests among Rounds 1 to 4 to see if the mean scores at each one of these rounds significantly differ from each other. Paired t-tests only showed a significant difference between Rounds 1 and 2, $t(48)= 2.269$, $p = 0.028$; and 3 and 1, $t(48)= 2.205$, $p = 0.032$.

Therefore, in an attempt to exclude the possible learning effect from Round 1, we decided to run another correlation analysis between average performance and the interoceptive levels taking into consideration only Rounds 2, 3, and 4 in the calculation. Still, no significant correlation was found between the average performance ($M = 61.75$, $SD = 31.13$, $n = 48$) and any of the performance levels. However, when we analyzed the rounds individually, we were able to find a significant positive correlation between awareness and performance in Round 3 only ($r = .316$, $n = 49$, $p = .027$). We also found a marginal positive correlation between accuracy and Round 3 ($r = .279$, $n = 49$, $p = .053$).

This result is interesting and might suggest that the influence of a factor (probably cognitive effort) was disrupting the correlation between performance and awareness. Nevertheless, the interpretation of this result is not so straightforward since there was no significant difference between the means of round 2, 3, and 4. Thus, it is also possible the correlation between awareness and performance depends also on an optimal level of stress (Kamata, Tenenbaum, & Hanin, 2002).

The lack of correlation between interoception and performance coupled with the findings of the correlation analyses between interoceptive awareness, presence, and body ownership led us to further investigate the differences between the EXP and DM conditions. Thus, we compared the results obtained in both conditions by running a series of four ANCOVAs with repeated measures to further explore how the relationship between presence, body ownership, and awareness is affected by each one of the conditions used in Study 1.

The analysis of covariance was performed only with awareness because it was the only variable that showed significant correlation with presence and body ownership. Presence, total presence, ownership, and EBO were each set once as dependent variables, with each condition set as independent variable, and interoceptive awareness as covariate. To allow a better visualization of the moderation effect we also decided to run each one of the ANCOVAs at three different levels of awareness: -.5, 0, and .5 (Figure 1).

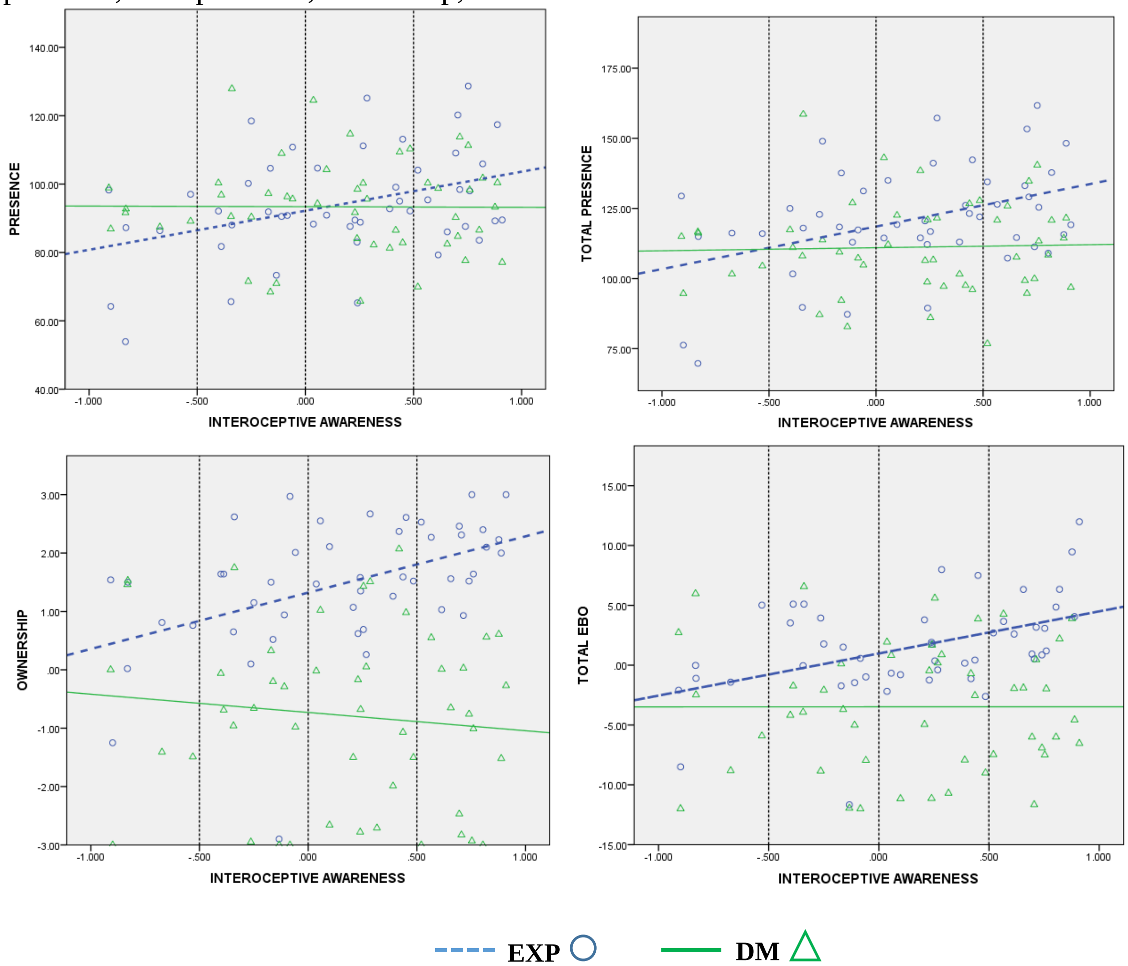
The first variable tested was presence. The analysis showed a marginally statistically significant effect of awareness on the conditions at $\alpha = .05$ ($F(1,46) = 3.239$, $p = .078$), with awareness having a significant effect on the "EXP" condition ($B= 10.579$, $t = 2.757$, $p= .008$, 95% C.I.= 2.855 to 18.304) but not on the "DM" condition ($B= 1.773$, $t= .508$, $p= .614$, 95% C.I.= -5.245 to 8.790). No significant difference between the means was found at the awareness level of .5 ($M_{exp\text{-}dm}= 3.108$, $p = .311$), 0 ($M_{exp\text{-}dm}= -1.295$, $p = .311$), or -.5 ($M_{exp\text{-}dm} = -5.698$, $p = .173$).

The second variable tested was total presence. The analysis showed once again a marginally statistically significant effect of awareness on the conditions at the $\alpha = .05$ ($F(1,46) = 3.423$, $p = .071$), with awareness having a significant effect on the "EXP" condition ($B=14.323$, $t = 3.064$, $p = .004$, 95% C.I. = 4.912 to 23.733) but not on the "DM" condition ($B=3.680$, $t = 0.849$, $p = .401$, 95% C.I. = -5.059 to 12.418). A significant difference between the means was found at the awareness level of .5 ($M_{exp\text{-}dm} = 13.033$, $p = .001$) and 0 ($M_{exp\text{-}dm}= 7.712$, $p = .018$), but not at the awareness level of -.5 ($M_{exp\text{-}dm} = 2.390$, $p = .624$).

The third and next variable tested was ownership. This time, the results of the analysis showed a statistically significant effect of awareness on the conditions at $\alpha = .05$ ($F(1,45) = 8.569$, $p = .005$), with awareness having a significant effect on the "EXP" condition ($B=1.014$, $t = 3.471$, $p = .001$, 95% C.I. = .426 to 1.603) but not on the "DM" condition ($B= -.360$, $t = -.814$, $p = .420$, 95% C.I. = -1.252 to .532). A significant difference between the means was found at the awareness level of .5 ($M_{exp\text{-}dm} = 2.641$, $p < .01$), 0 ($M_{exp\text{-}dm} = 1.954$, $p < .01$), and -.5 ($M_{exp\text{-}dm}= 1.267$, $p < .01$).

The final variable tested was total EBO. Similarly to ownership, the analysis showed a statistically significant effect of awareness on the conditions at $\alpha = .05$ ($F(1,46) = 5.611$, $p = .022$), with awareness having a significant effect on the "EXP" condition ($B=1.019$, $t = 3.454$, $p = .001$, 95% C.I. = 1.469 to 5.571) but not on the "DM" condition ($B= .091$, $t = .062$, $p =.951$, 95% C.I. = -2.864 to 3.045). A significant difference between the means was found at the awareness level of .5 ($M_{exp\text{-}dm}= 6.036$, $p < .01$), 0 ($M_{exp\text{-}dm} = 4.321$, $p < .01$), and -.5 ($M_{exp\text{-}dm}= 2.606$, $p = .038$). Figure 1 shows the different relationships between interoceptive awareness (the only measure to correlate with presence and EBO in the experiential task), presence and total presence, EBO for both experiential and decision-making conditions.

Figure 1. Differences in both conditions as to the relationship among awareness, presence, total presence, ownership, and EBO.



Although our findings do not support the hypothesis that there is a positive correlation between interoception and decision-making performance in performance-oriented VR games (H2), we believe that two factors may have influenced this result: 1) A possible mismatch between the interoceptive levels calculated via tracking task (instead of detection task) and the underlying characteristics required to perform in the DM condition, once the methods applied to calculate interoception do not result in equivalent results (Kleckner & Quigley, 2014; Kleckner et al., 2015); 2) The possibility that the type of decision-making task in the DM condition is not influenced by one's level of presence (Slater et al., 1996). Both aspects are further explored in Study 2.

Overall, these findings reinforce the need to explore the relationship between interoception and other behavioral aspects beyond the sole usage of accuracy and/or sensibility facets (i.e. by exploring interoceptive awareness), while also pointing to the need to explore VR experiences in different contexts, once the different focus of each game also produces experiences that are perceived emotionally and cognitively as different. Table 7 below summarizes all the results obtained in Study 1.

Table 7. Correlations found in Study 1 between interoception, presence, body ownership, and performance per per condition.

	EXP	DM
Tracking task		
Awareness and Total Presence – No support to H1a	r = .377, n= 49, p < .01	None
Awareness and Total Presence – No support to H1a	r = .412, n = 49, p < .01	None
Awareness and ownership – No support to H1b	r = .446, n = 49, p < .001	None
Awareness and Total EBO - No support to H1b	r = .454, n = 49, p < .001	None
Interoception and performance - No support to H2	Not Applicable	None

2.4 Discussion

Based on previous findings from Tsakiris, Tajadura-Jiménez and Costantini (2011), we first proposed a negative association between interoception, presence (H1a) and body ownership (H1b), taking into consideration all three interoceptive levels suggested by Garfinkel et al., (2015). No significant correlation was found between these levels which supports the idea that they are indeed distinct from each other as suggested by Garfinkel et., (2015) and Forkmann et al., (2016). Our results, however, did not support our first hypothesis, showing instead (and for the first time) a significant and positive correlation between interoceptive awareness, presence, and body ownership during experiential-oriented games. The correlation found between presence, body ownership, and awareness only seems to reinforce the importance of further exploring the level of awareness instead of focusing only on accuracy or sensibility. Such correlation may have been found because awareness intends to assess the extent to which one's confidence actually predicts one's accuracy by taking into consideration the relationship between beliefs and performance in heartbeat count (Forkmann et al., 2016).

In addition, we followed previous studies on the association between interoception and decision-making (Kirk, Downar, & Montague, 2011; Werner et al., 2009) to suggest a positive association between interoception and decision-making performance in performance-oriented VR games (i.e. DM condition) (H2). Our results also did not support this hypothesis, showing no significant correlation between the score obtained in the DM condition and any of the interoceptive facets even when we controlled for learning effect.

Although different aspects might have influenced the divergent results obtained with the EXP and DM conditions (e.g. non-presence of an avatar), we suspect that the type of emotion induced by the experiential game (i.e., thrill and fear) also contributed to the observed correlation between interoception and presence since interoceptive feelings generated by cardiac signals seem to selectively enhance the processing of fear and threat (Critchley et al., 2018). Moreover, the strong focus on visual-spatial abilities of the DM game selected, instead of a more natural and intuitive decision-making task, may have created physiological states that were poorly captured by the underlying psychological characteristics required to perform the tracking task. In other words, this result might have been different if we have used the detection task to calculate interoception instead (Kleckner & Quigley, 2014; Kleckner et al., 2015). Therefore, it is also possible that the contrasting results between the experiential and decision-making conditions might have been influenced by the method used to calculate interoception, since psychological processes unique to either tracking or detection task can influence the outcome of the three interoceptive levels and therefore, their relationship between themselves and with other variables (Jones, 1994; Forkmann et al., 2016; Ring & Brener, 2018). In Study 2, we attempt to replicate our results by further exploring how the differences between the two main methods of calculating interoception may influence the association between the levels of interoception, presence, EBO, and performance.

Finally, even if presence and interoception correlate, there is still the possibility that presence and performance do not correlate, since performance may or may not be grounded in the sense of presence (Slater et al., 1996). Thus, one possible explanation is that the underlying characteristics of certain VR experiences may induce physiological activations through "unnatural" states such as high cognitive effort, thus, disrupting the association between presence, body-ownership and performance. In Study 2, we further test this idea by adding a third decision-making condition focused on inducing a simple intuitive motor-prediction task (i.e. decide when to press a button to accurately hit a fast ball in a VR baseball game).

Therefore, although this first study provides an initial evidence of the association between interoceptive awareness, presence and EBO, it also highlights questions regarding core conceptual and methodological aspects of interoception, which need to be addressed to better understand how the three levels of interoception may associate with the two crucial aspects involved in assessing VR experiences (i.e. presence and body ownership). Thus, Study 2 aims at extending this exploration by examining the association between interoceptive levels calculated via its two main methods (i.e. tracking and detection respectively) and by further exploring how this association can be influenced by VR experiences with different underlying characteristics.

Chapter 3: Exploring methodological differences in interoceptive calculation and its impact on the relationship between interoception and VR experience

Our initial exploration of the relationship between interoception (via tracking task) and the senses of presence and body ownership (Study 1) revealed interesting findings regarding the association of awareness with VR experience but also raised questions regarding our findings that were specially related to two methodological limitations: 1) Regarding the interoceptive task used (i.e., tracking task only); 2) regarding the decision-making condition selected (i.e., visual-spatial task instead of an intuitive task).

To address these limitations, we designed Study 2. In this chapter we detail how we further explored the relationship between interoception (especially awareness), presence, EBO, and decision-making performance by using both methods to calculate interoception (i.e., tracking task VS. detection task). We collected data from 42 (valid) healthy participants who played the same two games used in Study 1 plus a third one (a decision-making VR game focused on intuitive motor-prediction abilities), which was added with the intent of exploring if an intuitive decision-making task would reveal an association between interoception, presence, and body ownership.

Study 2 provides evidence that the underlying psychological processes specific to either the tracking or detection task (also supported by participants' physiological reactions and subjective responses to these tasks) may not only create differences in each one of the levels of interoception but also seem to be associated with the specific characteristics of different VR experiences. Our findings provide an important contribution to the field of consumer research by providing evidence of how bodily feelings have an impact on consumer experience in virtual reality experiences. Moreover, our exploration of the three-level model and of the methods used to calculate interoception further helps to disentangle the conflicting findings and the conceptual misunderstanding still present in the study of interoception. Although Study 2 builds upon the findings and limitations of our first study, we also recognize the limitations of our findings. Yet, we raise awareness towards the relevance of consolidating the core methodological aspects of embodiment to advance VR research within the consumer behavior field. We also provide practical insights for VR designers on how bodily feelings may have an impact on VR experience, thus, assisting in the creation of a new generation of VR content and technologies.

3.1 Introduction to Study 2

Our exploration in Study 1 of the three levels of interoception, when calculated via the tracking method only, revealed a significant positive correlation between awareness, presence, and body ownership, with such significant correlation disappearing for the decision-making condition (i.e., a VR game that required the participant to perform a task within a certain time frame and was focused on visual-spatial orientation abilities). The contrasting results between the conditions used in Study 1 raised two important questions: 1) Could the results be affected by the method used to calculate interoception? 2) Could the lack of correlation in the decision-making task have been caused not only by the method used but also by the type of task in the decision-making game (i.e., visual-spatial vs. intuitive task)?

Therefore, the goal of Study 2 is to replicate and build on Study 1 by exploring how the outcome measures (i.e., accuracy, sensibility, and awareness) may differ depending on each of two main methods of calculating interoception (i.e., tracking and detection tasks) and how these outcomes then relate to the senses of presence, body-ownership, and performance. Moreover, we also address some of the issues regarding the decision-making condition used in Study 1 by adding a third performance-oriented game (i.e., baseball game in hit practice mode) that provided a simple and intuitive motor-prediction task, thus allowing us to further explore the impact of underlying characteristics of VR experiences in the association between interoception, presence, EBO, and performance.

There are currently two established measures to calculate interoception via heartbeat tasks: the heartbeat tracking task (Schandry, 1981; and Hart et al., 2013), which assesses accuracy by asking people to attend and silently count their heartbeats; and the heartbeat detection or discrimination task (Brener & Jones, 1974; Whitehead et al., 1977), which uses external stimuli (tones, lights, or tactile stimuli) to ask participants if the stimuli are in sync or not with their own heartbeats. The tracking task is the most accessible of the two tasks and it has been used in many studies to measure cardiac interoceptive accuracy (Kleckner et al., 2015). However, the method itself has been criticized for its lack of reliability caused by the influence of expectancies, time estimation, and different attentional aspects (Ring et al., 2015; Windmann et al., 1999). Moreover, although the outcome measures for both tasks are usually seen as conceptually interchangeable, previous research has provided evidence that they have different correlates, and thus should not be seen as equivalent (Cuenen, Diest & Vlaeyen, 2012; Kleckner & Quigley, 2014; Kleckner et al., 2015).

Forkmann et al., (2016) suggested that tracking and detection tasks differ in their required attentional processes since the tracking task requires the person to focus on visceral sensations while keeping track of one's heart beat count, while the detection task requires the person to focus on visceral sensations while noticing external signals to compare or discriminate their synchronization. Thus, previous studies also suggest that outcome results of correlations between the interoceptive levels themselves or between the levels and other variables will also be dependent on the interoceptive method used in the study (Schaefer et al., 2012; Hart et al., 2013; Forkmann et al., 2016).

Forkmann et al. (2016) showed that discrimination between the three-level model of interoception proposed by Garfinkel et al. (2015) also depends on the method used (i.e., tracking or detection task), with accuracy showing moderate correlations with the other levels when using the detection task. In fact, both studies seem to support the idea that psychological processes unique to either the tracking or the detection task can influence the outcome of the three interoceptive levels and the relationship between them. However, the results of the relationship between the levels are so far conflicting. Garfinkel et al. (2015) provided evidence to suggest that accuracy would be the central level of interoception and the only one associated with the other two levels, regardless of the method used to calculate them. But the results obtained by Forkmann et al. (2016) show only mild-correlations between accuracy and sensibility, and between accuracy and awareness when using the detection method only, with no significant correlation emerging when the levels were calculated via tracking task. Forkmann et al. (2016) suggested then that this stronger correlation between the levels when using the detection task may signal a higher sense of multisensory integration. Confidence judgment during the detection task, therefore, may be related to awareness of multisensory convergence (interoceptive-exteroceptive signals) while confidence judgment in the tracking task is solely related to interoceptive signals (and biased by time estimation and belief in one's own heart rate).

In Study 2, we thus propose the following hypotheses: The association between interoception and presence (H1a) and interoception and body ownership (H1b) is affected by differences in detection and tracking tasks; and differences in detection and tracking tasks also influence the association between interoception and performance in VR games (H2).

Finally, because interoceptive signals not only update predictions about the state of the body but also moderate the relationship between these bodily states and cognitive affective processes (Damasio, 1999), we also explore physiological markers that could reflect the different psychological processes unique to the tracking and detection task respectively. We chose Heart Rate Variablity (HRV) as the physiological marker to be explored since both detection and tracking methods are focused on cardiac attentional abilities. Moreover, Owens et al. (2018) have investigated how afferent interoceptive signals update predictions about the state of the body and moderate the emotional experience of anxiety in patients with forms of orthostatic intolerance (OI), a condition that leads to the development of signs, such as hypotension, and symptoms, such as lightheadedness, that occur when upright and are relieved by recumbence (Stewart, 2013). The results from Owens et al. (2018) showed a reduced interoceptive accuracy in OI groups (compared to a healthy control group) and a negative correlation between interoceptive awareness and high frequency HRV in OI groups when they were standing up. HRV markers are then able to some extent detect conflicts between experienced and expected interoceptive signals (i.e., prediction error), signaling when the person might be experiencing negative feelings (Owens et al., 2018; Paulus and Stein, 2006; Pollatos et al., 2007). In VR experiences, these negative feelings can reduce the sense of presence and even lead to cybersickness symptoms (Tanaka & Takagi, 2004). Therefore, exploring HRV markers may enable the development of better systems focused on reducing prediction error to optimize virtual reality experience, an idea supported by the results of

Gardé et al. (2018), which provide evidence that haptic feedback stimulation via vibro-kinetic seats seems to reduce cybersickness symptoms whilst improving presence in VR.

3.2 Method

3.2.1 Experimental Design and Procedure

The experimental procedure used in Study 2 was similar to the one used in Study 1. A single factor within-subject experimental design was again created, however, two important additions marked our second study: (1) The interoceptive levels were calculated via both detection and tracking tasks; (2) a third decision-making VR game (DM 2) focused on intuitive motor-prediction abilities was added and randomized with Games EXP and DM 1 used in Study 1.

Selected participants were informed of the experimental procedure and were asked to read and sign an informed consent form. Participants were then asked to sit comfortably for one minute while their Resting Heart Rate was measured using a GO2 finger clip oxymeter (Respironics Inc., PA, USA), placed on their left index finger. After the Resting Heart Rate measurement, participants were fitted with ECG electrodes and asked to complete both the detection and the heartbeat tracking task (in random order), followed by a confidence judgment task on each of their heartbeat counts (i.e., interoceptive sensibility). Finally, participants were instructed to wear the VR headset and briefed on how to play the three randomly assigned games. All participants also had a training session to get accustomed to the controllers used in the experiment.

The additional game (DM 2), called MLB The Show 18 (SIE San Diego Studio, USA) was selected due to its simplicity, enabling us to test how the characteristics of the DM 1 game (SuperHyperCube, Kokorami Collective) may have had an impact on the association between interoception, presence, body-ownership, and decision-making performance. Therefore, in Study 2 we used Study 1 conditions: the experiential game ("EXP"), and two performance-oriented games ("DM 1" and "DM 2"). The DM 2 game is a baseball simulation game in which participants played in "practice mode" with the sole intent of correctly hitting the ball. The DM2 game task required the participants to correctly predict when to hit the ball by pressing a single button. Successful scores depended more on focused attention and motor prediction to infer the best moment to press the hit button then on visual-spatial abilities which are more prominent in Game DM 1 (SuperHyperCube, Kokorami Collective). To simplify the task as much as possible, we decided not to use the original game scores since they took other variables within the game into consideration (e.g., home run scores were higher than other scores, even though in both cases the participant was able to correctly hit the ball). Scores were computed as follows: miss = 0 points, foul (i.e., hitting the ball but having it landing outside the marked area) = 1 point, hit (i.e., hitting the ball and having it land within the marked area) = 2 points. Finally, after playing all games, participants were asked to complete the presence scale (Witmer and Singer, 1998) and a body ownership scale based on Suzuki et al. (2013) and Aspell et al. (2013).

3.2.2 Participants

Forty-four healthy individuals (valid number = 42; 24 males [57.1%]; mean age = 28.69 years; SD = 7.49; range = 19-46) participated in the study, with two participants being removed from the analysis due to insufficient completion of the questionnaires. All participants were recruited via the school's panel and the study was approved by the school's ethics committee prior to its beginning. Participants received a gift card worth $30 as compensation on the completion of the experiment, which took approximately 2 hours to complete.

3.2.3 Experimental Setup

Participants once again sat facing a 50-inch TV at an approximate distance of 3 feet. The chair was fastened to the floor to avoid extreme movements and to ensure participants' safety in the event of an intense movement during the main experiment. To create the immersive virtual reality experience, we used a PlayStation^{TM} VR system console along with AKG K77 Pro Audio headphones to induce an immersive sound experience and two PS4 movement detection controllers to simulate touch and movement experience. A feed-forward PS4 camera was mounted above the TV and aligned with the participant's face in order to provide its exact location and ensure a correct visual angle.

ECG signals were monitored using BITalino's ECG system (Plux Inc., Lisbon, Portugal) and three Ag-AgCl electrodes, and a Polar H10 HR-monitor (Polar, USA) was used to measure heart rate variability (HRV). The system's sampling frequency is of 100Hz, bandwidth of 0.5-40 Hz, signal resolution of 10 bits, and voltage range of ± 1.5mV. R-waves were visualized in real-time using OpenSignals software. Electrode placement was done accordingly to Němcová et al.'s (2016) suggestion, with the positive electrode being placed under the right clavicle the negative electrode at the lower left lateral chest approximately under the left musculus pectoralis major, and reference electrode under the left clavicle. The ECG equipment collected peak systolic activity (i.e., peak R-waves); it was used both to collect data during the heartbeat tracking task as well as to send the auditory cardiac feedback while the participants performed the detection task.

To calculate interoception via the detection task, an in-house software was built using the Java coding language. The software allowed us to set the Synchronous signal at 230ms after peak R-wave and Asynchronous cardio feedback signals at 530ms (130%) after peak R-wave (Forkmann et al., 2016). The decision regarding the Synchronous signals was also based on previous evidence that participants judge stimuli presented during the peak activity of aortic barorepectors (i.e., between 100-300ms after peak systolic activity) to be more synchronized with their own cardiac activity (Brener, Liu, & Ring, 1993; Ring et al., 2015, Suzuki et al., 2013). Sinus tone during the detection task was set at 440 Hz and 80ms of duration, with 6 tones per trial, and a total of 20 synchronized trials and 20 asynchronous trials per participant. The signal was verified in real-time and electrode adjustment and replacement was done in 2 cases due to extremely noisy data probably caused by the participants' greater body mass (i.e., situations in which R-waves and noise were not possible to differentiate from each other). Finally, based on Aspell et al. (2013), we also coded our software to enable us to do individual threshold adjustments in an attempt to guarantee maximum detection accuracy and optimal signal amplitude.

3.2.4 Measures

The three levels of interoception were calculated using both tracking and detection methods following Garfinkel et al. (2015) and Forkmann et al., (2016). The three interoceptive levels were measured before participants played the games and filled out the questionnaire. Below we describe each of the measurements in detail for each method:

Tracking task

- **Accuracy**: Accuracy was measured using the Schandry heartbeat tracking task (Schandry, 1981), equivalent to the protocol of our last study (see Study 1). Participants received the following instruction: "Please, count silently each heartbeat you feel in your body from the time you hear "start" to when you hear "stop" without manually checking your pulse". Task instructions were given by the researcher seated behind a one-way mirror. We used different randomized durations (25, 30, 35, 40, 45, 50 seconds). During each period the ECG system recorded and streamed in real-time their actual R waves, which were used to calculate the accuracy score after each trial according to Hart et al.'s (2013) algorithmic transformation:

  {1 – (|nbeatsreal - nbeatsreported|)} / {(|nbeatsreal + nbeatsreported|)/2}

  An average was computed from the six trials scores resulting in a final accuracy score ranging from -1 to +1, with moderate differences between actual and perceived heartbeat ranging from 0 to 1, while negative differences signaled extreme differences between perceived and actual heartbeat (Forkmann et al., 2016).

- **Sensibility**: After each trial participants were asked to judge how confident they were that their heartbeat estimation was correct. Confidence judgment was registered by using an online visual continuous scale from 0 to 10 displayed on an iPad with its left extremity marked as "total guess/no heartbeat awareness" and the right extremity labeled "complete confidence/full perception of heart beat". Interoceptive sensibility was then calculated for each participant as the mean of the six confidence judgments (Garfinkel et al., 2015; Forkmann et al., 2016). No feedback was provided in terms of the participants' performance during the experiment.

- **Awareness**: Awareness, according to Garfinkel et al. (2015), is a measure of the extent to which the participants' confidence in their perceived heartbeat count can predict their own actual performance in the task. Therefore, for the tracking task we calculated the Awareness score of each participant by performing within-participant Pearson's correlations between confidence and performance score over all six trials.

Detection task

- **Accuracy**: Accuracy was measured following Forkmann et al. (2016) guidelines, and based on the original task created by Brener and Jones (1974). Participants were asked to judge at the end of each one of the 40 rounds (by voicing out loud) if they perceived the exteroceptive stimuli (e.g., auditory tone) to appear as either "synchronous" or "asynchronous" with their own heartbeats. Accuracy was measured using *d'* parameter derived from signal detection theory (SDT), which can be applied whenever two different types of stimulus presented are to be discriminated (Stanislaw & Todorov, 1999). Correctly identified synchronous trials were marked as "hits", and asynchronous trials mistakenly identified as synchronous were defined as "false alarms". Thus, accuracy was measured according to the following formula:

  d': $Z_{hits} - Z_{falsealarms}$ *; where Z is the standardized value of the variables.*

  Larger absolute values of *d'* signify a greater sensitivity to the difference between the synchronized and desynchronized signals, with *d'* values near zero indicating chance performance. Thus, *d'* values basically represent how good the participant is in accurately detecting the synchronized signals.

- **Sensibility**: After each trial of the detection task, participants were asked to judge how confident they were of their decision (i.e., synchronous or asynchronous) on an online visual continuous scale from 0 to 10 using an iPad with its left extremity marked as “total guess/not sure at all” and the right extremity labeled “complete confidence/absolute sure”. Following Forkmann et al. (2016), the confidence score in the detection task needs to converge with the accuracy test and thus was only used to assess trials judged to be synchronous, either correctly (“hits”) or incorrectly (“false alarms”).

- **Awareness**: Awareness was calculated for each participant according to Garfinkel et al. (2015) guidelines. We calculated the area under the curve (AUC) using the receiver operating characteristics (ROC) curve analysis, with accuracy set as the binary outcome and the confidence judgments as dimensional predictor. The ROC curve was calculated using University of Chicago LabROC software (Pesce, Papaioannou, and Metz, 2011). The software allowed us to use a semi-parametric estimation approach and Conventional Binormal Model to create and use the fitted curve (using one thousand fitted points) instead of the empirical curve (which uses only the forty points – number of rounds in the detection task – to draw the curve).

  We followed the method applied by Garfinkel et al. (2015) to calculate awareness using the correct identification of whether the tones were synchronous or asynchronous with the participant’s heart as the state variable and their confidence judgment as the test variable. This calculation of awareness in terms of correct judgment of synchronicity provided us with an index of the degree to which one’s confidence would predict the ability in differentiating correct synchronous versus asynchronous tones.

Heart Rate Variability (HRV)

Heart Rate Variability (HRV) is a product of the autonomic nervous system (ANS) regulation of the sinoatrial node, a bundle of specialized neurons located in the right atrium responsible for the natural pace of the heart of about 60 to 70bpm in normal resting conditions (Tarvainen et al., 2013; Ernst, 2016). Therefore, quantitative analysis of HRV reflects important heart-brain interactions mediated by both ANS sympathetic and parasympathetic systems (Valderrama, Navarro, & Le Van Quyen, 2010). The influence of these systems in both heart rate and HRV are well understood with, in a basic sense, situations such as mental stress, anxiety, or fear increasing HR and reducing HRV via the sympathetic nervous system, while situations such as rest and meditation being related to decreases in HR and increases in HRV (Takahashi et al., 2005; Tarvainen et al., 2013). In this study we analyzed HRV both in terms of frequency and time domain, as follows:

High Frequency (HF-HRV): In healthy individuals, this is the most noticeable band in HRV frequency analysis. It is also known as Respiratory Sinus Arrhythmia (RSA), meaning it is a respiratory related activity that reflects the function of the vagus nerve in increasing HR during inspiration and decreasing it during exhalation (Berntson et al., 1997). The HF-HRV band (0.15Hz to 0.40Hz) is believed to be more reliable than the low frequency band as it is mediated by a great extent by parasympathetic nervous activity (Tarvainen et al., 2013), however it is still to some extent influenced by sympathetic activity (Billman, 2013).

Low frequency (LF-HRV): This band (0.05Hz to 0.15Hz) is a component of HRV that has a complex nature because it is influenced by both sympathetic and parasympathetic systems, and it has been frequently shown to positively correlate with baroreceptor sensitivity (i.e., the fast modulation of HR in response to changes in the tension of the arterial wall caused by variations in blood pressure) (Owens et al., 2018; Malik & Camm, 1993; Goldstein et al., 2011). However, previous studies have suggested that normalized units of the low frequency component (i.e., relative value of the power of the component in proportion to the total power minus the very low frequency component) could be used to measure sympathetic efferent activity (Owens et al., 2018; Takahashi et al., 2005). Low frequency component is also positively correlated with muscle sympathetic nerve activity (Pagani et al., 1997), and negatively correlated with enhanced internalized attention during Zen meditation practices (Takahashi et al., 2005).

Root Mean Square of Successive Differences (RMSSD): This is a time domain statistical method that refers to the root mean square of successive differences in NN intervals, also known as normal beat-to-beat or RR intervals (i.e., intervals that do not take into consideration abnormal phenomena) (Owens et al., 2018). It is seen as a measure of vagus-mediated autonomic control of cardiac activity similar to HF band and is associated with short-term variability and fast changes in HR (Tarvainen et al., 2013; Stein et al., 1994). Reductions in RMSSD have been shown to reflect a decrease in parasympathetic activity and an increase in sympathetic tone (Valderrama, Navarro, & Le Van Quyen, 2010).

3.2.5 Scales

Presence was assessed according to the 24-item scale created by Witmer and Singer (1998) while body ownership was measured using the 4-item scale based on Suzuki et al. (2013) and Aspell et al. (2013) (Appendix A). Reliability of both presence and EBO scales (see Figure 2 for descriptive statistics) were conducted in a series of exploratory factor analyses for all three conditions. As expected, EFA analysis for the scale failed to produce a satisfying factor structure, producing cross-loadings and low item-loadings per factor probably due to its low subject-to-item ratio (lower than 2:1) (Costello & Osborne, 2005).

Following Study 1 and based on Witmer and Singer (1998), the 19 initial questions of the presence scale once again formed the *Presence* scale (which does not take into consideration the questions regarding the evaluation of sound and touch experiences), while the *Total Presence* scale was formed by using the full 24-item scale, with items 20 to 22 assessing sound experience and items 23 and 24 assessing touch experience.

The EFA for the total presence scale in the EXP condition (KMO = .664, Sphericity < .001), revealed items 22 and 23 to have loadings below .2 in the single factor structure. However, the reliability index after removal of the items provided little to no increment (initial Cronbach's alpha was of .887, and Cronbach's alpha after item removal varied between .888 and .879). Thus, we decided to keep all the items for a richer analysis. Reliability for the 19 initial items (i.e., presence score) tested via Cronbach's alpha was .862.

EFA for the presence and total presence scale during the DM 1 condition (KMO = .758, Sphericity < .001), also showed all items loading above .3 (except for items 17 and 22). All items were again kept since Cronbach's alpha with all items included was .895 and removal of items 22 and 17 produced a decrease of .002 to a small increment of .06. The reliability score via Cronbach's alpha for presence scale (i.e., Q1 to 19) was also .895.

Finally, EFA for total presence for DM 2 (KMO = .711, Sphericity < .001), had all items loading above .3 (except for item 14 to 18). Again, all items were retained since Cronbach's alpha with all items was .934, and removal of these items produced a maximum increment of only .004 in reliability. Cronbach's alpha for presence scale (i.e. Q1 to 19) was .901.

The EFA for the EBO scale during the EXP condition supported the 2-factor structure (control vs ownership scale), with items 1 and 3 (ownership subscale) loading on Factor 1 (respective loads = .929, .858) and items 2 and 4 (control subscale) loading on Factor 2 (respective loads = .351, .954). Cronbach's alpha for the whole scale during the EXP condition was .568 and Cronbach's alpha for the ownership questions was .848 (corrected item-total correlation = .737).

EFA for the DM 1 condition also showed 2-factor structure with items 1 and 3 (ownership subscale) loading on Factor 1 (respective loads = .852, .880) while items 2 and 4 loaded on Factor 2 (respective loads = .952, .692). The Reliability test via Cronbach's alpha for the whole scale during the DM 1 condition was .682 (corrected item-total correlation > .358). Cronbach's alpha for the ownership questions during EXP was .731 (corrected item-total correlation = .577).

Finally, EFA for DM 2 condition again confirmed the 2-factor structure of the EBO scale with items 1 and 3 (ownership subscale) correctly loading on Factor 1 (respective loads = .891, .870) while items 2 and 4 loaded on Factor 2 (respective loads = .810, .859). The Reliability test via Cronbach's alpha for the whole scale during the DM 2 condition was .730 (corrected item-total correlation > .456). Cronbach's alpha for the ownership questions during EXP was .771 (corrected item-total correlation = .631).

3.3 Results

3.3.1 The Three-Level Model of Interoception per Method

We tested the three-level model by performing a correlation analysis between the outcome measures (i.e., interoceptive levels) of each task (Table 8). Similar to our first experiment, and in agreement with Forkmann et al. (2016), we found no significant correlation between the three levels of interoception when calculated either via tracking, and only a moderate strength correlation between accuracy and sensibility via the detection task (r = -.336, n = 42, p = .029).

Table 8. Correlation between interoceptive levels of both tracking and detection task.

		Accuracy (tracking)	Sensibility (tracking)	Awareness (tracking)	Accuracy (detection)	Sensibility (detection)	Awareness (detection)
Accuracy (tracking)	r	1					
	p						
	n	42					
Sensibility (tracking)	r	0.190	1				
	p	0.227					
	n	42	42				
Awareness (tracking)	r	0.015	-.027	1			
	p	0.927	.866				
	n	42	42	42			
Accuracy (detection)	r	0.131	-.158	-.118	1		
	p	0.408	.318	.455			
	n	42	42	42	42		
Sensibility (detection)	r	-0.108	.664**	.104	-.336**	1	
	p	0.496	.000	.512	.029		
	n	42	42	42	42	42	
Awareness - (detection)	r	0.086	.178	-.131	-.013	-.049	1
	p	0.587	.260	.410	.934	.760	
	n	42	42	42	42	42	42

However, contrary to Forkmann et al. (2016), the direction of the correlation we found between accuracy and sensibility was negative, probably influenced by the participants' difficulty in performing the detection task with confidence. Moreover, no significant correlation between accuracy and awareness was found when they were calculated via detection task. Finally, a significant positive correlation between the two measures of interoceptive sensibility ($r = 0.664$, $n = 42$, $p < 0.001$) was revealed in the analysis, suggesting the possible presence of a general level of interoceptive confidence across the tasks (Garfinkel et al., 2015).

Age and resting heart rate also did not show any significant correlation with the interoceptive variables in either the detection or the tracking task. However, using Miles and Shevlin (2001) guidelines for effect size using eta-squared index, we observed that biological sex showed a significant medium strength association with accuracy in the detection task ($\eta^2 = 0.19$; $M_{male} = 0.351$, $SD_{male} = 0.469$; $M_{female} = -0.864$, $SD_{female} = 0.437$, $F = 9.454$, df = 39, $p = 0.004$) and significant small strength association with sensibility in the tracking task ($\eta^2 = 0.11$; $M_{male} = 6.06$, $SD_{male} = 1.96$; $M_{female} = 4.67$, $SD_{female} = 1.94$, $F = 5.141$, df = 39, $p = 0.029$) only. Still, no significant correlation was found between accuracy in detection task and resting heart rate or age, nor between sensibility in the tracking task and resting heart rate or age when we performed a partial two-tailed correlation controlling for biological sex (as dummy variable).

We also ran a series of t-tests to compare the means of the heart rate variability time and frequency domain (i.e., RMSSD, LF, and HF) collected during each task. The tests showed a significant difference between the tasks in terms of low frequency ($M_{Det\text{-}Trak} = 8.49$, SD= 8.37, $t(39) = 6.414$, $p < .001$) and high frequency HRV levels ($M_{Det\text{-}Trak} = -8.46$, SD= 8.36, $t(39) = 6.393$, $p < .001$). However, no significant difference was found between the tasks when the means of RMSSD were compared ($M_{Det\text{-}Trak} = 1.10$, SD = 7.63, $t(39) = .915$, $p=.366$). Table 9 presents the differences and correlations found between the tracking and detection tasks.

Table 9. Overall correlation and differences between tracking and detection task.

DESCRIPTIVES	**Tracking task**		**Detection task**
Number of trials per participant (structure)	6 (25s, 30s, 35s, 40s, 45s, 50s – randomized)		40 (20 at 230ms, 20 at 530ms – randomized)
Accuracy- hart/d' (SD)	Hart: .70 (.19)		d': .16 (.50)
Sensibility (SD)	5.46 (2.05)		6.35 (1.50)
Awareness (SD)	.040 (.56)		.56 (.20)
SIG. CORRELATIONS (between tasks)			
Sensibility and Sensibility	r = .664, n = 42, p < .001		
T-tests (HRV values)	**Tracking task**	**Detection task**	**Det-Trak (M / SD / t / Sig. 2-tailed)**
RMSSD (SD)	43.82 (24.73)	44.41 (22.90)	1.10 / 7.63 / .915 / .336
Low frequency (SD)	64.55 (16.29)	73.17 (14.13)	8.49 / 8.37 / 6.414 / .000
High frequency (SD)	35.40 (16.27)	26.80 (14.09)	-8.46 / 8.36 / 6.393 / .000

3.3.2 Presence, EBO, and Performance Scores per Condition

Comparisons of means between all games (i.e., experiential-oriented game "EXP", visual-spatial matching-form game "DM 1", and the intuitive motor-prediction baseball game "DM 2") showed a higher average presence score for DM 1 (98.09, see Figures 2 and 3 for a plot of all means of presence and body ownership for each condition), with statistically significant differences found between the means of Games DM 1 and DM 2 (M_{DM1-2} = 31.08, SD = 27.79, t(41) = 7.246, p < .001) and between games EXP and DM 2 ($M_{EXP-DM2}$ = 26.94, SD = 23.93, t(41) = 7.295, p < .001), but not between DM 1 and EXP (M_{1-2} = 4.13, SD = 19.81, t(41) = 1.353, p = .184). However, when sound and touch questions were added to the scale to form the total presence score, the EXP condition showed the highest average score (122.89), with once again significant differences between the means of EXP and DM 2 ($M_{EXP-DM2}$ = 40.26, SD = 28.79, t(41) = 9.061, p < .001) and between the means of games DM 1 and 2 (M_{DM1-2} = 35.95, SD = 33.74, t(41) = 6.905, p < .001), but not between games EXP and DM 1 ($M_{EXP-DM\ 1}$ = 4.31, SD = 24.25, t(41) = 1.153, p = .256).

The analysis of the means of ownership showed the EXP game once again as the condition with the highest mean score (1.86), with the comparison of the means showing a significant difference for mean ownership score between games EXP and DM 2 ($M_{EXP-DM2}$ = 2.92, SD = 1.70, t(40) = 10.982, p < .001), between games DM 1 and DM 2 (M_{DM1-2} = 1.05, SD = 1.78, t(40) = 3.724, p = .001), but also between games DM1 and EXP ($M_{EXP-DM1}$ = 1.98, SD = 1.82, t(40) = 6.946, p < .001). The addition of the control question to form the total body ownership (total EBO) scores produced a similar pattern, with the games EXP and DM 2 greatly influenced by the control questions (M_{EXP} = 4.06, M_{DM2} = -5.43) and with game DM 1 being the least influenced by them (M_{DM1} = -.70). A comparison of the means also showed a significant difference between the three means for total EBO ($M_{EXP-DM1}$ = 4.42, SD = 5.89, t(41) = 4.866, p < .001; $M_{EXP-DM2}$ = 9.28, SD = 6.05, t(41) = 9.938, p < .001; M_{DM1-2} = 4.85, SD = 5.22, t(41) = 6.019, p < .001).

Figure 2. Means (and paired comparisons) for presence, total presence per condition.

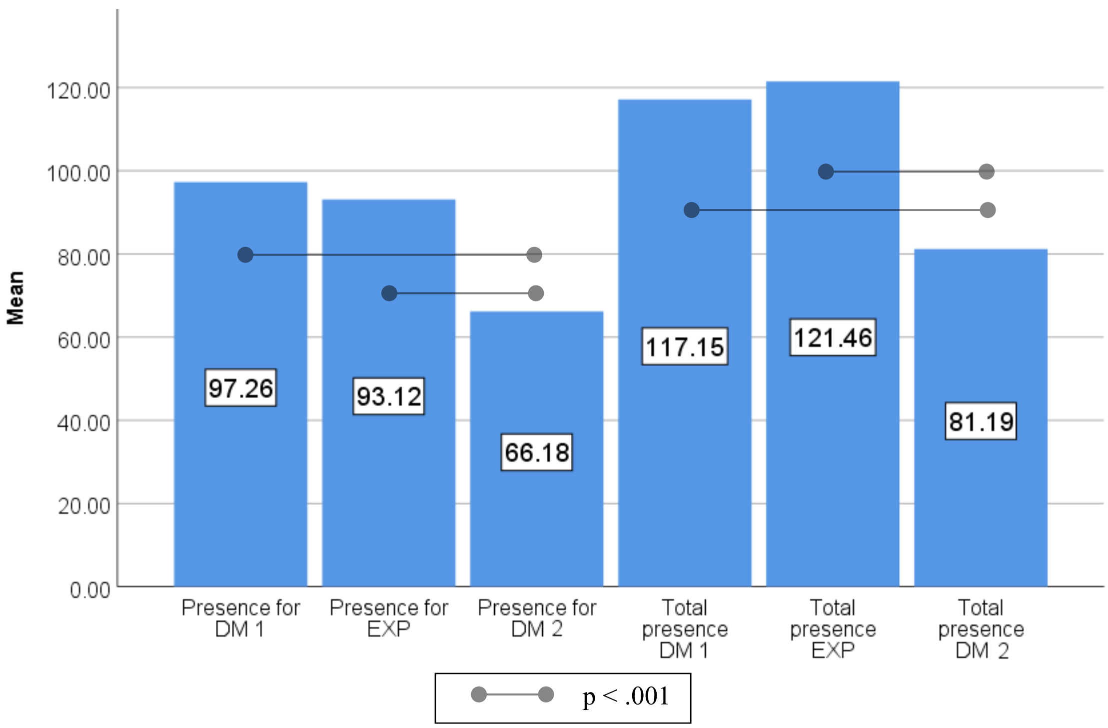
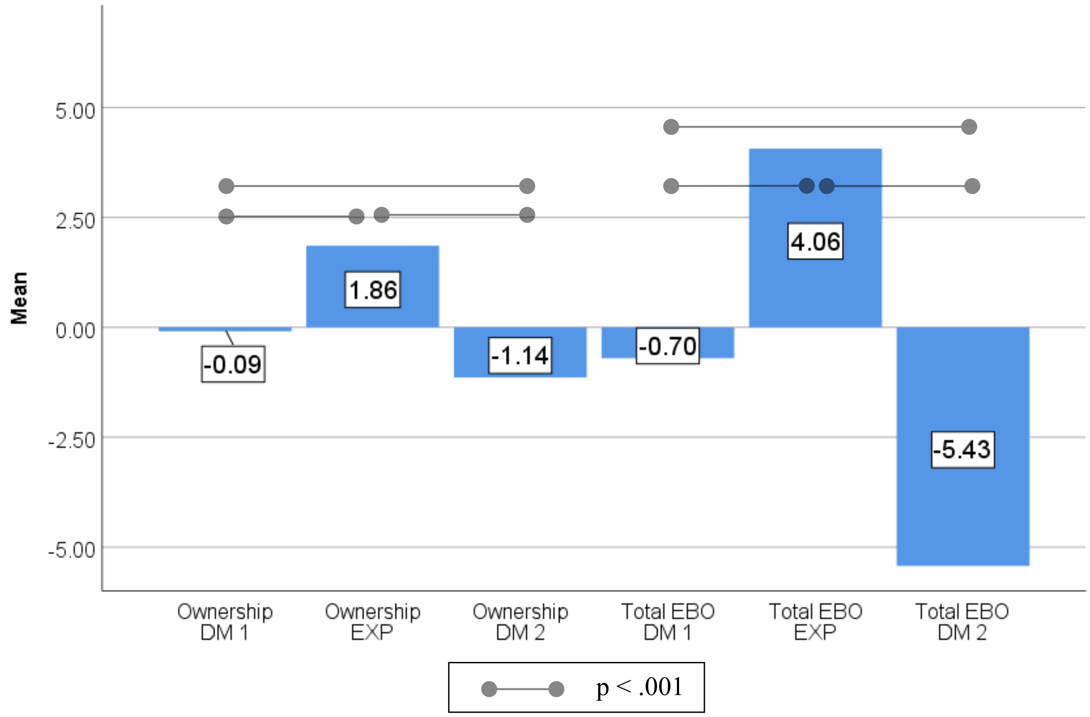


Figure 3. Means (and paired comparison) for ownership and total body ownership (EBO) per condition



We also performed an initial analysis to explore how the factors of presence and body ownership relate to the scores obtained in both the performance-oriented games. Participants' HRV frequencies were also added to the analysis as an attempt to investigate the underlying physiological aspects related to the experience of each performance-oriented VR experience.

No significant correlation was found between performance in DM 1 and either presence, body ownership, or any HRV variables. A result that was still constant when we control for age and biological sex. The analysis of the performance for DM 2, however, displayed different results, showing a positive and significant correlation between performance and presence ($r = .429$, $p = .005$, $n = 41$), as well as between performance and total presence ($r = .371$, $p = .017$, $n = 41$). No significant correlation was found between performance and body ownership, nor between performance and any of the HRV variables for game DM 2, even when we controlled for age. However, a correlation analysis controlling for biological sex showed a marginal correlation between performance for DM 2 and HF-HRV ($r = -.299$, $n = 38$, $p = .061$), LF-HRV ($r = 299$, $n = 38$, $p = .061$), and RMSSD ($r =$

-.288, n = 38, p = .071). Yet, no significant differences were found between the means of males and females for any of the HRV variables.

Interestingly, DM 2 showed higher HF-HRV (M_{DM2-1} = 6.66, SD = 10.28, t (41) = 4.200, p < .01) and RMSSD (M_{DM2-1} = 7.54, SD = 11.14, t(41) = 4.390, p < .01), but lower LF-HRV (M_{DM2-1}= -6.69, SD = 10.13, t(41) = -4.282, p < .01) than game DM 1, a frequency pattern that indicates greater parasympathetic activity for DM1 (Tarvainen et al., 2013). These results might explain the negative direction of the correlation when controlling for biological sex since optimal performance demands optimal levels of stress for the task (Kamata, Tenenbaum, & Hanin, 2002). Moreover, the results of the analysis of the means of the HRV variables indicate DM 2 to be less stressful than DM 1, probably caused by a greater mental effort required to play DM 1 than DM 2 game, and thus misguiding the experience of the internal bodily signals towards an aversive state (Paulus and Stein, 2006) and disrupting the correlation between presence and performance for DM 1. Moreover, because presence and ownership scores were significantly greater for game DM 1 than for DM 2 (Table 10), this result supports view that the relationship between presence and performance is not solely dependent on how high or low levels of presence are for each game, but on how grounded performance is on presence (Slater et al. (1996).

Table 10. Mean comparisons for presence, body ownership, HRV, and performance between decision-making conditions DM 1 (visual-spatial) and DM 2 (intuitive motor task).

	DM 1 (M / SD)	**DM 2 (M / SD)**	**1 – 2 (M / SD / t / Sig. 2-tailed)**
Presence	97.25 /17.25	66.17 /21.86	31.08 / 27.79 / 7.249 / .000*
Total Presence	117.14/21.52	81.19 /27.23	35.95 / 33.74 / 6.905 / .000*
Ownership	-.125 / 1.87	-1.18 / 1.58	1.05 / 1.78 / 3.724 / .001*
Total EBO	-.671 / 5.36	-5.52 / 4.97	4.85 / 5.22 / 6.019 / .000*
Rmssd	52.48 / 29.70	60.03 / 37.56	-7.54 / 11.14 / -4.390 / .000*
High Frequency	29.76 / 13.03	36.43 / 15.93	-6.66 / 10.28 / -4.200 / .000*
Low Frequency	70.17 / 13.03	63.47 / 15.96	6.69 / 10.13 / 4.282 / .000*
Performance (raw score)	57.35 / 35.45	11.14 / 9.33	Non-applicable comparison
Performance (normal)*	3.975 / 1.83	3.967 / 2.55	.007 / 2.62 / .019 / .985

**Transformation was used since raw scores were not comparable: (y = 1 + (x-A)*(10-1)/(B-A); where A-B is the range of the data. Scores standardized to a scale of 1 to 10 (maximum performance).*

Altogether, the results above suggest that the type of VR experience has an impact not only on the levels of presence and body ownership sensed during the games, but also on the association between presence, performance, and HRV. This creates a much more complex view of the topic and may help unveil the divergences found in Study 1. In the next sections we further explore this finding by investigating the impact of interoception on the variables of presence, body ownership and performance.

3.3.3 Trend analysis

We once again performed a trend analysis to check for order effects such as fatigue or carry-over. This time, however, we also performed an analysis of variance at alpha .05 to also compare the means of the levels of interoception according to the order of the task performed (i.e., detection first VS. tracking first). The analysis showed no significant difference in the order of tasks performed for interoceptive accuracy ($M_{DET-TRAK}$ = .047, F(1,40) = .586, p = .448), sensibility ($M_{DET-TRAK}$ = .119, F(1,40) = .033, p = .857), or awareness via tracking task ($M_{DET-TRAK}$ = -.063, F(1,40) = .124, p = .727). The order of the method used also had no impact on interoceptive accuracy ($M_{DET-TRAK}$ = -.245, F(1,40) = 2.515, p = .121), sensibility ($M_{DET-TRAK}$ = -.295, F(1,40) = .382, p = .540), or awareness via detection task ($M_{DET-TRAK}$ = -.003, F(1,40) = .002, p = .96).

Order effect was also not statistically significant when we verified the impact of the order of conditions played (i.e., EXP, DM1, DM2) on presence for DM1 [F(5,36) = 1.033, p = .413], EXP [F(5,36) = 1.033, p = .413], or DM2 conditions [F(5,36) = 1.069, p = .393]. No significant order effect was found either for total presence for DM1 [F(5,36) = .850, p = .524], EXP [F(5,36) = 1.068, p = .394], or DM2 condition [F(5,36) = .938, p = .468].

The analysis also showed that the order of the conditions played by the participants had a marginal significant effect on ownership for DM1 [F(5,35) = 2.143, p = .083] and DM2 [F(5,35) = 2.210, p = .075] and a significant effect on ownership for EXP condition [F(5,36) = 2.588, p = .042]. This result is similar to what was found in Study 1 and once again we believe that it reflects the importance of first-person perspective (i.e., “from where I perceive the world”) in Bodily Self-Conciouness (Blanke, 2012). All conditions had different perspectives, with the DM1 not providing the participants with an avatar in first-person perspective as did the EXP condition, and the DM2 providing the participants with a third-person perspective. This is supported by the significant differences on the mean ownership score (see section 3.3.2) in which EXP (first-person avatar) > DM 1 (no avatar) > DM2 (third-person avatar). This aspect then probably induced the participants to experience a contrast in ownership sensations. Finally, there was no significant order effect on performance scores for DM 1 [$F(1,40) = .013$, $p = .911$]. However, an interesting order effect appears on performance scores for DM2 [$M_{DM2\text{-}DM1} = .7.292$, $F(1,39) = 7.094$, $p = .011$]. The fact that the effect was observed only for performance scores in the DM2 condition together with the observed difference between groups (i.e., DM2 first > DM1 first) made us believe that such an effect could have been caused by a possible attention depletion when playing the DM1 game first (i.e., the visual-spatial decision-making game). This is supported not just by the differences between the tasks but also by the HRV patterns (see section 3.3.2) that shows DM1 to induce greater sympathetic and lower parasympathetic activity than DM2 (the intuitive DM game).

3.3.4 The Impact of Different Interoceptive Methods on the Association Between Presence and the Three Levels of Interoception (H1a)

To investigate our first hypothesis that the association between interoception and presence is influenced by differences in tracking and detection tasks (H1a), we first ran a series of correlations between the levels of both methods and presence scores for each of the three conditions (see Table 12 for a summary of all findings in this section). Initial results showed no significant correlation between any of the interoceptive levels and presence scores when using the tracking task, in contrast to the results of Study 1. However, the correlation analysis using the interoceptive levels calculated via the detection task showed a marginal positive correlation between awareness and presence ($r = .289$, $n = 42$, $p = .063$) and between awareness and total presence ($r = .301$, $n = 42$, $p = .052$), however, this correlation was found for game DM 1 only. Correlation controlling for age and biological sex also did not reveal any significant result for either the detection or tracking task.

Because of these unclear findings, we considered it relevant to further explore the conflicting results found in Studies 1 and 2. We then first explored the data from the tracking task and compared the means of the presence scores between both studies, using only information from the conditions that were used in both cases (i.e., EXP and DM 1).

The result of the comparison of the means revealed no significant difference between either presence or total presence scores, showing that the presence score for the conditions was held relatively constant across studies (Table 11). Interestingly, the analysis of the means between the interoceptive levels of both studies showed a higher mean for both accuracy and sensibility for Study 2 in comparison to Study 1. Interoceptive awareness, the only variable that was lower for Study 2, did not significantly differ between the studies.

Since the t-tests showed no difference in the means of awareness between the studies, we wondered if the lack of replication of the results in Study 1 could have been caused not by different levels of awareness but by a different distribution of the awareness scores between the studies (i.e., values concentrated more towards the higher or lower end of its distribution curve). Thus, we decided to turn to the median as a measure of central tendency, which showed a higher and positive value for awareness in Study 1 (.241) and a lower negative median for Study 2 (-.119).

Table 11. Mean comparisons for presence scores between Studies 1 and 2 using tracking task.

	Study 1 (M / SD)	**Study 2 (M / SD)**	**1 – 2 (M / SD / t / Sig. 2-tailed)**
Accuracy	.587 / .26	.698 / .195	-.111 / .334 / -2.161 / .037*
Sensibility	4.55 / 2.14	5.47 / 2.05	-.912 / 3.106 / -1.903 / .064*
Awareness	.179 / .548	.039 / .561	.139 / .783 / 1.153 / .256
Presence (DM 1)	92.92 / 12.95	97.26 / 17.26	-4.34 / 23.67 / -1.187 / .242
Presence (EXP)	94.52 / 15.53	92.87 / 16.91	1.64 / 18.91 / .556 /.581
Total Presence (DM 1)	110.59 / 14.73	117.14 / 21.53	-6.55 / 27.29 / -1.556 / .127
Total Presence (EXP)	121.24 / 19.20	121.23 / 19.20	.013 / 23.70 / .003 / .997

The body of literature contains a large number of studies that revealed significant correlations and statistical effects by splitting groups in terms of low and high interoceptive levels (e.g., Knoll & Hodapp, 1992; Tsakiris, Tajadura-Jiménez, & Constantine, 2011; Suzuki et al., 2013; Garfinkel et al., 2015; Lenggenhager, Azevedo, Mancini & Aglioti, 2013) and not by the verification of the continuous data set. Taking these approaches into consideration we decided to further analyze the difference between high and low interoceptive awareness by dichotomizing the data. Compared to the detection task, the data set for the tracking offered us a second challenge since the correlation pattern between awareness, presence, and ownership for the tracking task showed not only greater dispersion but also followed a cubic function. Thus, we first attempted to dichotomize the data into high and low awareness levels using the interquartile range as a method for selecting only the above-floor level of awareness while avoiding the mid distribution of the data. However, the interquartile range (.94) left us with only 5 data points, and this would drastically increase the possibility of spurious correlation. We then turned to the standard deviation (.55) (± 1 SD) to select groups "high" and "low", which gave us groups with 15 points of data while still avoiding the mid distribution.

After dividing the sample into groups of high and low awareness, we turned once again to the correlation analysis using the interoceptive levels calculated using the tracking task and found a significant and positive correlation between awareness and presence ($r = .616$, $n = 15$, $p = .014$), as well as between awareness and total presence ($r = .586$, $n = 15$, $p = .022$) for the high group during EXP game only. This result converges with the findings of Study 1. A regression analysis also showed awareness to be a significant predictor of presence ($B = .616$, $p = .014$) and total presence (Adj. R2 = .293; $F[1,13] = 6.804$, $p = .022$) for the EXP game, with a statistically significant quadratic model (Adj. R2 = .332; $F[1,13] = 7.953$, $p = .014$) (Figure 4 and 5). The scores of the low awareness group showed no significant correlation with either presence or total presence under any condition.

Figure 4. Quadratic relationship between awareness (via tracking task) and presence (Q1 to Q19) for high awareness group during EXP condition.

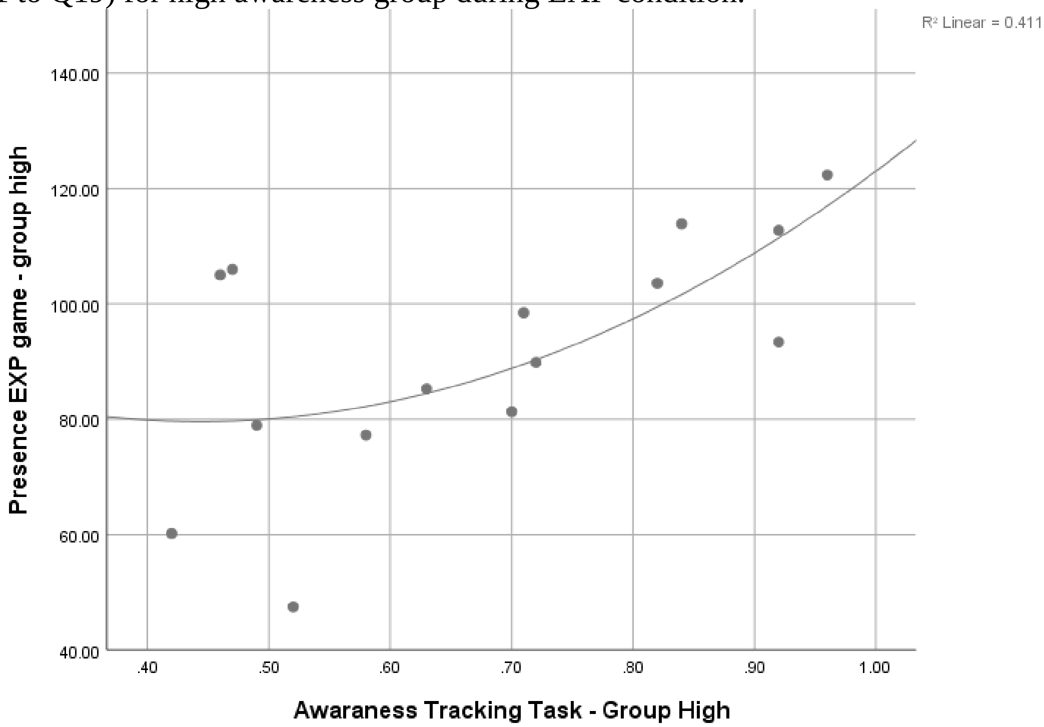
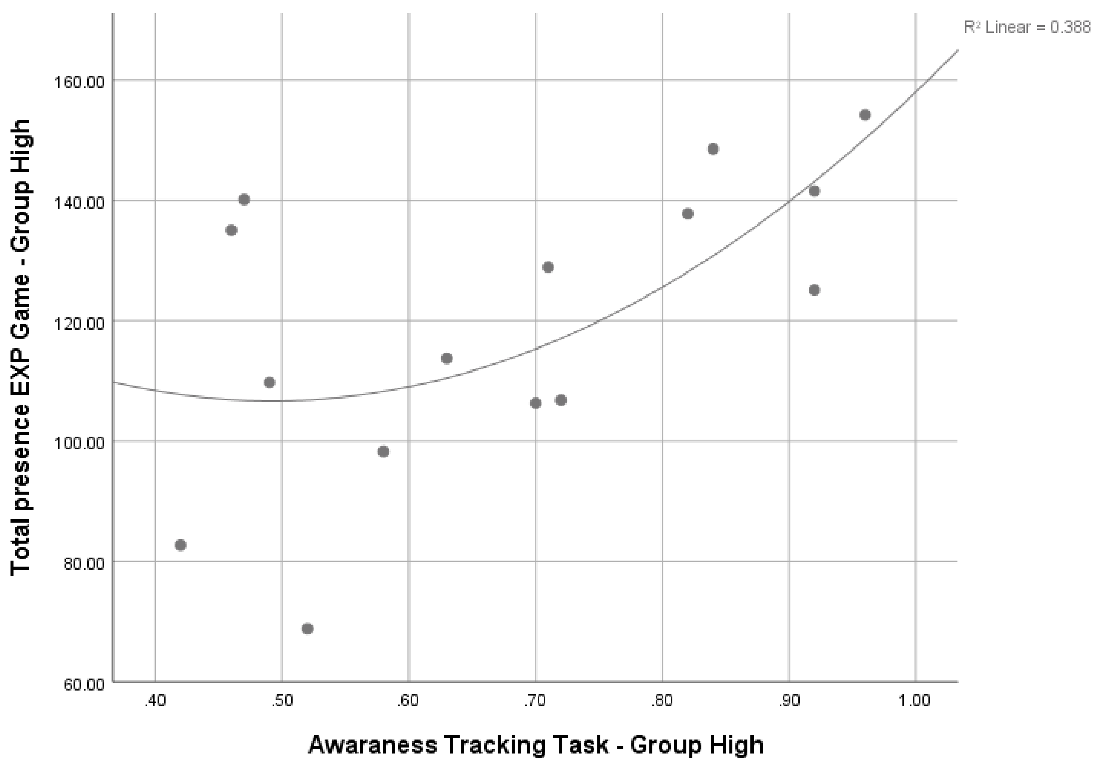


Figure 5. Quadratic relationship between awareness (via tracking task) and total presence (Q1 to Q24) for high awareness group during EXP condition.



Dichotomization was also performed to further explore the results from the detection task. For the detection task, we used a traditional median split approach to generate the groups since the low variability in awareness via the detection task clustered all values close to each other, leaving us with only 4 to 5 variables per group if we decided to use SD or interquartile range, also increasing the possibility of spurious correlations. The results revealed a positive and significant correlation between awareness and presence ($r = .619$, $n = 22$, $p = .002$), as well as between awareness and total presence ($r = .578$, $n = 22$, $p = .005$) for the low group during game DM 1 only, suggesting that the initial positive correlation found between presence and awareness via the detection task is actually being induced by the low awareness group. No other significant correlation was found between presence and awareness for either the high or low group taking into consideration games EXP or DM 2.

A hierarchical regression analysis was performed to test the quadratic function of the association between presence and awareness via detection tasks. Presence was set as the dependent variable, awareness as the independent variable, and awareness squared set in the second block in order to assess the possibility of a threshold effect. The results for group "low" showed awareness to be a significant predictor of presence for during game DM 1 ($B = .589$, $p < .01$), with the increment of awareness squared in the model resulting in a significant change (R^2 Change = .296, $F[1,17] = 14.028$, $p < .01$) and the combined model having almost twice the adjusted R^2 of the linear model (Adj. $R^2 = .600$; $F[2,19] = 15.236$, $p < .001$) (Figure 6). A similar result was also perceived with total presence, with awareness as a significant predictor of total presence ($B = .546$, $p =.013$) and the increment of awareness squared resulted in a significant change (R^2 Change = .303, $F[1,17] = 12.909$, $p < .01$), with the combined model having more than double the adjusted R^2 of the linear model (Adj. $R^2 = .554$; $F[2,19] = 12.793$, $p < .001$) (Figure 7).

Figure 6. Relationship between awareness (via detection task) and presence (Q1 to Q19) for low awareness group at game DM 1.

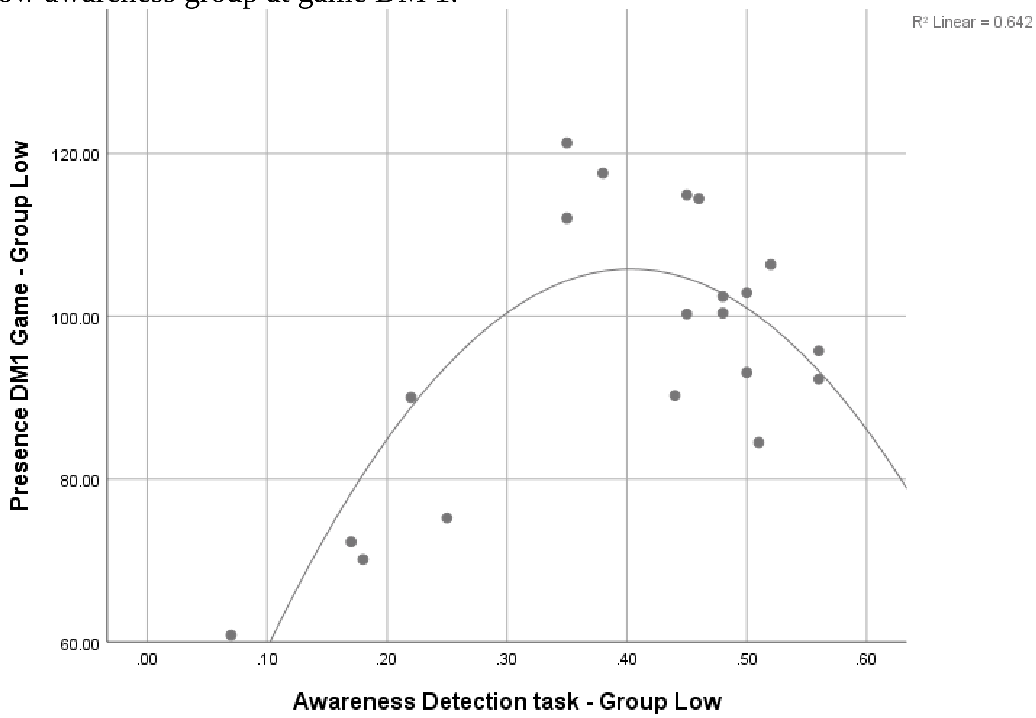
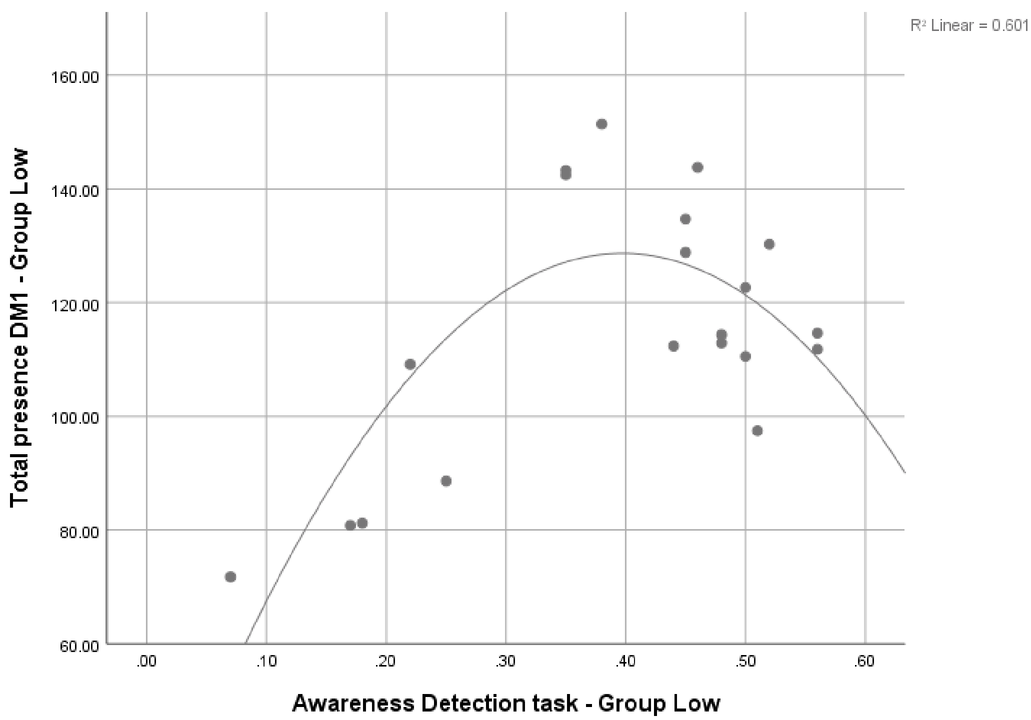


Figure 7. Relationship between awareness (via detection task) and total presence (Q1 to Q24) for low awareness group at game DM 1.



Altogether, the results support H1a revealing that the association between interoception and presence seems to be influenced by the method (i.e., tracking and detection task) used to calculate the interoceptive levels. Moreover, despite the EXP game having a higher mean presence than the other two games, it only significantly differed from DM 2 ($M_{EXP-DM2}$ = 40.26, SD = 28.79, t (41) = 9.061, p < .001), with no significant difference found when compared to DM 1 ($M_{EXP-DM1}$ = 4.31, SD = 24.25, t (41) = 1.153, p = .256). This result indicates that even if awareness is consistently positively associated with presence, conflicting findings might appear due to the influenced of stimuli and method selection. Thus, our results also point to the possible existence of a match between the characteristics of VR game and the distinguished attentional processes that are unique to perform either the tracking or detection task (Forkmann et al., 2016; Ring & Brener, 2018). Table 12 provides a summary of the differences in the correlations found between interoception and presence per method and condition.

Table 12. Summary of the correlations found in Study 2 between interoception and presence per interoceptive method and condition.

	EXP	DM 1	DM 2
Tracking task			
Awareness and presence*	r = .616, n = 15, p = .014	-	-
Awareness and total presence*	r = .586, n = 15, p = .022	-	-
Detection task			
Awareness and presence**	-	r = .289, n = 42, p = .063	-
Awareness and total presence**	-	r = .301, n = 42, p = .052	-
Awareness and presence***	-	r = .619, n = 22, p = .002	-
Awareness and total presence ***	-	r = .578, n = 22, p = .005	-

** For group high only; **whole sample; *** For group low only.*

3.3.5 The Impact of Different Interoceptive Methods on the Association Between EBO and the Three Levels of Interoception (H1b)

To investigate H1b, which proposes that the association between interoception and EBO is also affected by the method used to calculate interoception, we again performed a series of correlations this time between EBO scores and the three levels of interoception calculated via both tracking and detection tasks (see Table 13 for a summary of all findings in this section). The analysis of the tracking task revealed only a positive and significant correlation between ownership for game DM 1 and sensibility ($r = .374$, $n = 41$, $p = .016$). This association was, however, diminished when a partial correlation controlling for biological sex was performed ($r = .297$, $n = 38$, $p = .063$). No other significant correlation was found between the interoceptive levels via tracking task and ownership or total EBO for any of the games.

However, when using the data from the detection task, we were able to confirm a significant and positive correlation between awareness and ownership ($r = .321$, $n = 41$, $p = .041$) and a positive and significant correlation between awareness and total EBO for game DM 1 only ($r = .311$, $n = 41$, $p = .045$). The latter, was probably influenced by the small variance added by the scores obtained with the control question, as shown by a comparison between the means of the ownership factor and total EBO for game DM 1 ($M_{ebo\text{-}own} = -.636$, $SD = 3.97$, $t(40) = 1.026$, $p = .311$). Similarly to the tracking task results, we also observed a positive correlation between sensibility and ownership in game DM 1 ($r = .318$, $n = 41$, $p = .043$), probably influenced by the high correlation between the sensibility scores of tracking and detection task and which was once again diminished when the influence of biological sex was controlled ($r = .294$, $n = 38$, $p = .066$). These initial results provide us with at least with marginal evidence that the methods to calculate the levels of interoception also have an impact on their association with body ownership (H1b).

However, taking into consideration the results found in the investigation of H1a after dichotomizing the data, we found it relevant to follow the same procedure in order further explore the lack of correlation between body-ownership and awareness (via the tracking task) during the EXP condition of Study 2. The results of the correlation analysis after dichotomizing the data in low and high awareness partially converged with the ones found in our first study, showing a marginally significant correlation between high awareness group and ownership for EXP game ($r = .497$, $n = 15$, $p = .071$), but not between group high and total EBO ($r = .141$, $n = 15$, $p = .631$) - an evidence that the addition of control questions in the total EBO reduced the strength of the relationship between awareness and body ownership. No other correlation was found for either group high or low awareness in either game using the tracking task.

Interestingly, when we performed a median-split analysis using awareness calculated via detection task, we found only a positive correlation between awareness and ownership in DM 1 for the low awareness group (r = .465, p = .045, n = 19), a result congruent with the analysis of the association between presence and awareness via detection task. No other significant correlation was found between awareness and ownership for the high or low group. Table 13 summarizes the correlations found in the investigation of H1b.

Table 13. Summary of the correlations found in Study 2 between interoception and EBO per interoceptive method and per condition.

	EXP	DM 1	DM 2
Tracking task			
Sensibility and ownership**	-	r = .374, n = 41, p = .016	-
Awareness and ownership *****	r = .497, n = 14, p = .071	-	-
Detection task			
Sensibility and ownership**	-	r = .318, n = 41, p = .043	-
Awareness and ownership******	-	r = .321, n = 41, p = .041	-
Awareness and ownership *******	-	r = .465, n = 19, p = .045	-

** For group high only; **whole sample; *** For group low only*

Our findings converge with the analysis of H1a, indicating that the association between interoception and body ownership is at least partially affected by the method used to calculate the interoceptive levels while also indicating a possible match between the characteristics of the VR experience and the attention processes unique to each method.

Interestingly, the test of non-linearity of the relationship between awareness via tracking task and ownership for EXP game (using the full data set via hierarchical regression analysis with awareness squared and cubic being tested in blocks 2 and 3 respectively) showed that awareness in a linear model was not a significant predictor of ownership (B = .160, p = .312; Adj. R^2 = 0.001; F[1,40] = 1.047, p = .312).

However, the increment of the cubic model showed not only a greater significance (R^2 Change = .157, F[1,38] = 8.638, p = .006) than the quadratic model (R^2 Change = 0.129, F[1,39] = 5.926, p = .020) but also a greater combined effect for its significant model (Adj. R^2 = .256; F[3,38] = 5.711, p = .003) than just the addition of the quadratic model (Adj. R^2 = .111; F[2,39] = 3.511, p = .038).

The test of non-linearity between awareness (group high) via tracking task and ownership for EXP game showed that awareness within a linear model was a marginal predictor of ownership (B = 4.571, p = .071; Adj. R^2 = .184; F[1,13] = 3.932, p = .071) with the increment of the quadratic model to improve the prediction model (Adj. R^2 = .243; F[2,11] = 3.086, p = .086), but with the improvement not large enough to be significant (R^2 change = .113, F[1,11] = 1.933, p = .192) (Figure 8).

When the test of non-linearity was performed between awareness (group low) via detection task and ownership for DM1 game, the results showed awareness within a linear model to be a significant predictor of ownership (B = 7.240, p =.045) and the increment of awareness squared to result in a significant change (R^2 Change = .223, F[1,16] = 6.352, p = .023), with the combined effect having more than the double of the adjusted R^2 than the linear model only (Adj. R^2 = .369; F[2,16] = 6.264, p = .001) (Figure 9). This result is convergent with the analysis performed for H1a, indicating that the behavior of awareness as a predictor of presence and body ownership might also be influenced by a threshold effect.

Figure 8. Relationship between awareness and ownership factor for EXP condition (media split) for the tracking method.

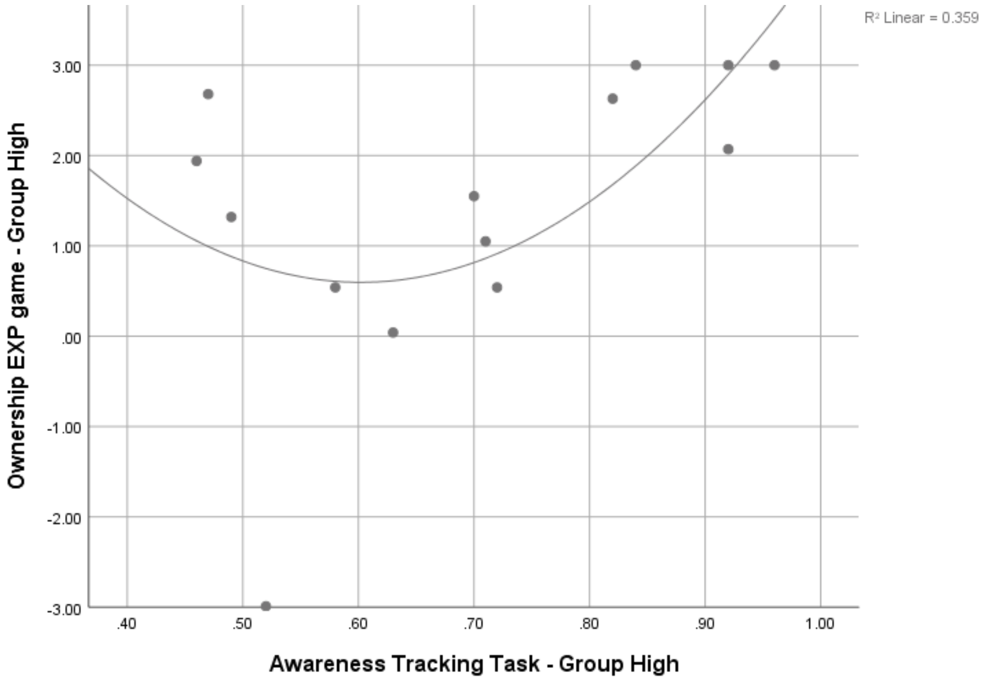
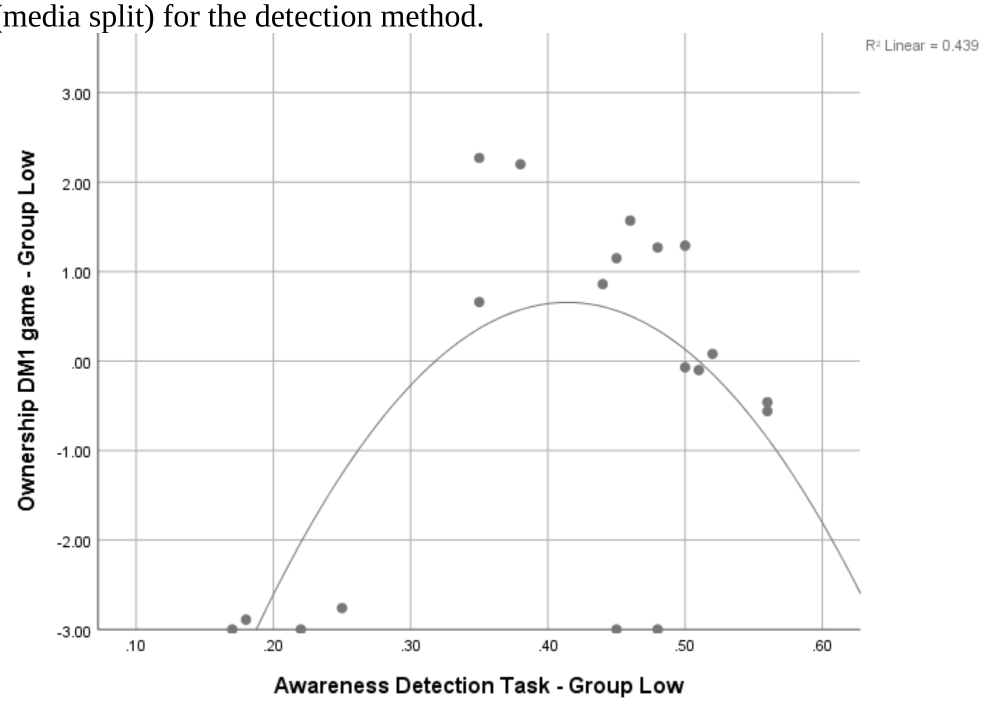


Figure 9. Relationship between awareness and ownership factor for EXP condition (media split) for the detection method.



Altogether, the above results provide at least marginally support to H1b, showing that the relationship between interoception and body ownership may be affected by differences between the detection and tracking task. To some degree our results also add another layer of complexity to the topic by showing that awareness (instead of accuracy) via tracking task positively correlates with body ownership for group high and in the EXP condition only. This result contrasts with Tsakiris Tajadura-Jiménez, & Constantine (2011) by showing that the association between awareness for group low and body ownership was found only via detection task (instead of via tracking task) and for the DM 1 condition only. This suggests that the association between interoception and body ownership seems to also depend on the matching between the characteristics of the VR experience and the underlying psychological processes involved in performing each interoceptive task (i.e. tracking vs. detection task). Thus, in the next section we investigate this aspect by exploring the association between interoception and performance.

3.3.6 The Impact of Different Interoceptive Methods on the Association between Decision-Making Performance and the Three Levels of Interoception (H2)

Finally, to investigate how differences in detection and tracking tasks also have an impact on the association between interoception and performance in VR games (H2), we first performed a correlation analysis between the interoceptive levels calculated via tracking task and performance in DM1 and DM2. The results showed no significant relationship between any of the variables (but see Table 14 for a summary of all the findings in this section).

However, due to a small strength association between biological sex and sensibility in the tracking task ($\eta^2 = 0.11$; $M_{male} = 6.06$, $SD_{male} = 1.96$; $M_{female} = 4.67$, $SD_{female} = 1.94$, $F = 5.141$, $df = 39$, $p = .029$), we decided to also perform a correlation analysis controlling for biological sex. The result of the partial correlation, although marginally significant, revealed an increase in the strength of the association between sensibility and score in DM 2 ($r = -.279$, $n = 41$, $p = .08$). We believe that such correlation might have been influenced by the males' tendency to rely more intensely on their physiological reactivity than females when asked to report their emotions in a controlled environment (Robert &

Pennebaker, 1995). Note, however, that biological sex had only a marginal effect on performance in DM 2 ($M_{male-female}$ = 20.43, F[1,40]=3.635, p =.064) and none in DM 1.

Interestingly, the correlation analysis using the outcome variables of the detection task method, revealed a positive and significant correlation between performance in game DM 2 and accuracy (r = .326, n = 41, p = .037). A marginally significant correlation between performance for game DM 1 and sensibility was also revealed when controlling for age (r = .267, n = 39, p = .091), a result that follows Kandasamy et al. (2009) findings about the impact of age on interoception.

To further explore this result, we performed an analysis of covariance with score for DM 1 as dependent variable, interoceptive sensibility as covariate and age, divided into two groups (above and below the median 27.50), as fixed factor. The results revealed age to have a significant impact on performance for DM 1 at the 5% level (F(1,39) = 5.431, p = .025, observed power = .623) with younger participants (below median age, n = 21) performing better than the older participants (M_{diff} = 23.691, SE = 10.166, p = .025, 95% C.I. = 3.129 to 44.253). Age, however, had no impact on the scores for DM 2. Finally, no significant correlation was found between awareness (via either tracking or detection task) and performance for either the high or low group of awareness.

Table 14. Correlations found in Study 2 between interoception and performance per interoceptive method per condition.

	DM 1 (visual-spatial)	**DM 2 (intuitive motor task)**
Tracking task		
Sensibility and score (controlled for biological sex)	-	r = -.279, n = 41, p = .08
Detection task		
Accuracy and score	-	r = .326, n = 41, p = .037
Sensibility and score (controlled for age)	r = .267, n = 39, p = .091	

Altogether, our results support H2, providing evidence that the relationship between interoception and performance is affected by the method used to calculate the interoceptive levels, but that the association between interoception and performance -

similarly to the association between interoception, presence, body ownership – also seems to depend on the matching between the characteristics of a certain type of VR experience and the psychological processes that underlie the different interoceptive methods. Moreover, our findings also suggest that the association between performance and interoception is independent of the correlation between presence, body ownership and interoception. Such proposition has a relevant impact at both conceptual and practical levels, suggesting that efforts to enhance presence as a way of enhancing performance can be misleading since one may only be able to increase performance to the extent to which the task selected is grounded on presence (Slater et al., 1996).

3.4 Discussion

In Study 2 we further explored how the feelings that arise from internal bodily signals may influence the VR experience, with our results supporting our hypotheses that the different methods used to calculate interoception (i.e., tracking vs. detection task) have an impact on the association between presence, ownership, performance and interoception. Here we provided evidence (given the limitations of dichotomization) that the association between presence, body-ownership, and interoception is influenced not only by differences between the three interoceptive levels (see Study 1), but also by the type of interoceptive method used to calculate them (i.e., tracking or detection task). Moreover, we also provide evidence to suggest that the association between interoception and performance is not dependent on the level of presence experienced in each game, but instead on how grounded this performance is on presence (Slater et al., 1996).

In Study 2, we found awareness via tracking task (for the group with high awareness only) to significantly correlate with presence and total presence in the experiential-oriented VR game, while awareness via detection task (for the group with low awareness only) revealed significant correlations with both presence and total presence in the visual-spatial decision-making game (DM1) only. Although there is no straightforward interpretation of the different quadratic relationships between tracking and detection task, we believe that this finding is a possible evidence of how the underling psychological processes unique to interoceptive methods (Forkmann et al., 2016; Ring & Brener, 2018) may interact with the types of games and affect the relationship between interoception and presence. More specifically, since tracking task is influenced by expectancies, time estimation, and different attentional aspects (Ring et al., 2015; Windmann et al., 1999) it is possible that the correlation between the high awareness group and the experiential game reflects the match between expectation and emotional intensity driven by the characteristics of the game. In contrast, the detection task is seen as a more reliable task that depends almost exclusively on the detection of the heartbeat sensations (Ring & Brener, 2018). Thus, because only the group with low awareness showed a positive correlation between awareness via detection task and presence in the visual-spatial decision-making game, it is possible that this result points to the existence of an optimal level of awareness in which awareness above such point may break the sense of presence by shifting the interpretation of the signals towards a maladaptive sensation of cognitive effort.

A similar pattern of correlations was also found between awareness and body ownership, with ownership marginally correlating with awareness via tracking task (for group high only) in the experiential-oriented VR game, and significantly correlating with awareness via detection task (for both whole data set and group low) in the visual-spatial decision-making game DM1 only. Altogether, these results supported (at least marginally) our initial hypothesis that the association between interoception, presence (H1a) and body ownership (H1b) is affected by differences in detection and tracking task.

We suggest that the significant relationship found between ownership and sensibility, for both detection and tracking tasks, was influenced by the correlation between both measures of sensibility as well as influenced by the participants' biological sex. The influence of biological sex on sensibility follows previous studies that evidence the effect of biological sex differences on confidence, self-reported emotions, and worry experience related to the sensation of internal bodily signals (Grabauskaitė, Baranauskas, & Griškova-Bulanova, 2017). In fact, in controlled environments, males demonstrate stronger reliance on their physiological reactivity than females when reporting their emotions as well as tend to have higher accuracy in detection task than females, a difference that disappears in more naturalistic settings (for a review see Robert & Pennebaker, 1995).

Moreover, the differences in the means of time and frequency domains HRV values for each interoception task (i.e., higher LF-HRV and lower HF-HRV for detection vs tracking) also point to the possibility that during the detection task, participants experienced greater mental effort (Börger et al., 1999) and increased self-focused attention but not necessarily greater accuracy in heartbeat estimation (Gaebler et al., 2013). In fact, at the end of the experiment, some of the participants stated their experience in performing the detection vs. the tracking task: 1) *"It was hard to concentrate on both my heartbeats and the sound at the same time";* 2) *"It was harder [detection task] because the sound disturbed my attention and concentration on my heart";* 3) *"It was harder for me to listen to the sound and feel my heart beat at the same time. In fact, it [the detection task] made me feel somehow anxious"*. Thus, the result supports the idea that interference by attending to both internal and external stimuli might be a particular issue in detection task (Couto et al., 2015) and that such difficulty can be seen in terms of physiological responses.

The same pattern in HRV frequency was also found when comparing DM 1 vs DM 2, possibily indicating lower levels of stress induced by the intuitive game DM 2. Interestingly, although presence and ownership scores were significantly greater for DM 1 than for DM 2, we found no significant correlation between the score for DM 1 and either presence or interoception. Only performance in DM 2 was shown to correlate with presence. We suggest that the type of decision-making task in DM 1 may be less grounded in the sense of presence (Slater et al., 1996) and more grounded in other cognitive abilities that are to a certain degree independent of the sense of presence. That being so, it is also possible that characteristics of the task in DM 1 (i.e., visual-spatial reasoning puzzle game) induced levels of cognitive effort that were strong enough to have an impact on the interpretation of the bodily signals and, thus, disrupt the association between presence and interoception as well as between interoception and performance.

Finally, the correlation found in DM 2 between accuracy (via detection task only) and performance, as well as between performance and presence, not only supports our hypothesis (H2) but also indicates a possible equivalence between the required skills to perform in game DM 2, presence, and the multisensorial attention to internal and external sensations required to accurately perform the detection task (Forkmann et al., 2016; Garfinkel et al., 2015). Thus, overall the results of Study 2 suggest that the association between interoception, presence, and body ownership reflects the matching or not of the VR experience with the underlying psychological process required by the different heartbeat methods. In the next chapter we further discuss the overall findings of our Study 1 and 2, as well as state both theoretical and managerial contributions, and the limitations and future research venues.

Conclusion

General Discussion

In general terms, this thesis attempts to further extend our knowledge of how feelings that arise from internal bodily signals (i.e. interoceptive) interact with other senses to shape one's perception of reality in the context of VR games. Moreover, by also exploring interoception via detection task (which requires an ability to focus on internal and external signals simultaneously), we also extend the knowledge of integrative sensations that have an impact on VR experience. However, the understanding of how interoceptive feelings influence other senses depends first of an agreement on the core conceptual and methodological aspects of the topic.

In Study 1, we explored the relationship between presence, body ownership, and the three levels of intereoception (i.e., accuracy, sensibility, awareness) calculated via the most accessible method (i.e., tracking task). Our investigation led to the evidence that, of all three levels, only awareness was positively associated with presence and body ownership, and such correlation was only revealed during the experiential-oriented VR game (i.e., game focused on free interaction with the environment, without any pressure to perform). These results and the limitations of our findings generated two main questions: 1) Could our findings be influenced by the method used to calculate interoception? 2) Could the lack of correlation in the decision-making task have been caused not only by the method used but also by the type of task in the decision-making game? In other words, could the results be different if the decision-making task selected were an intuitive decision-making task instead of one focused on visual-spatial abilities?

Thus, in Study 2, we further investigated the results of Study 1 by exploring how the interoceptive levels calculated via the two main methods (tracking and detection tasks) relate to presence and body ownership. We also added a second performance-oriented game, a simple and intuitive motor-prediction task, to further explore how the underlying characteristics of a game might have an impact on the association between presence, interoception, and performance. The results showed awareness to be positively associated with presence and body ownership but with an interesting twist: The correlations found between interoception, presence, and body ownership varied according the method used to calculate interoception and they seemed to consistently match with different games (i.e., outcomes from the tracking task were associated with the experiential conditions while the outcomes from the detection task with the visual-spatial reasoning game). Moreover, performance, presence, and interoception significantly correlated this time, but only when exploring the intuitive motor prediction performance-oriented game (vs. the visual-spatial reasoning game). Interestingly, the intuitive decision-making game was also the one with the lowest level of presence of all three conditions explored, but it had HRV patterns that suggested it to be less stressful for the participants. This result might suggest that the visual-spatial decision-making game, by requiring higher cognitive abilities, induced levels of cognitive effort that were high enough to generate an aversive interpretation of the user bodily signals. This idea is supported not only by the lack of correlation between interoception and performance for the visual-spatial reasoning game ("DM 1") found in both our studies, but also by the correlation found between the low awareness group and presence in the same condition, meaning that the association between presence and interoception was somehow disrupted in participants with high levels of interoceptive awareness. Finally, this result may also support Slater et al.'s (1996, p. 166) idea that not all performance tasks are grounded in presence, and thus not always affected by the levels of presence:

"It is posing the wrong question to consider whether presence per se facilitates task performance. Rather presence brings into play "natural" reactions to a situation (which may or may not have something to do with efficiency of task performance) - and the greater the extent to which these natural reactions can be brought into play the greater that presence is facilitated, and so on. It isn't really a question of how good the performance is, but rather how it is grounded in presence."

Theoretical Implications

Thus, our paper offers three main contributions. First, our results consolidate the idea of a three-level model of interoception (Garfinkel et al., 2015) and extend the knowledge of the core aspects of VR experience (i.e., presence and body ownership) by providing evidence across our two studies of the relationship between these variables and also by demonstrating how this relationship seems to depend on the interoceptive level and VR experience being used in the analysis. In fact, by exploring all the three levels and not just accuracy – the most commonly used of the three levels – we support the importance of measuring awareness in research as well as the proposal of Owens et al. (2018, p. 69) "that most experiments have been using the least relevant measure of interoception".

Second, we also extend the knowledge on the integration of multisensorial information (Krishna and Schwarz, 2014) by comparing the different outcome measures from both tracking and detection tasks (Ring & Brener, 2018; Jones, 1994; Suzuki et al., 2013; Forkmann et al., 2016). This comparison provides methodological recommendations in assessing VR experience via interoceptive sensations, and we hope will also motivate further studies on the relationship between interoception, presence, and body ownership, as well as provide further evidence of the association of these variables with other aspects such as decision-making (Kirk, Downar, & Montague, 2011; Werner et al., 2009; Sütterlin et al., 2013) and physiological reactivity (Gaebler et al., 2013; Takahashi et al., 2005; Börger et al., 1999).

Third, the different correlations found between performance and interoception via tracking and detection tasks also extend our knowledge about human attention and perception. Our results indicate that accurate perception and confidence in bottom-up attention processes from afferent internal bodily sensations might be relevant in some contexts, such as to guide fast and accurate motor decisions in simplistic contexts, but not in others which seem to be more affected by top-down attention aspects such as reasoning and visual-spatial abilities and thus rely more on higher cognitive skills. In fact, we believe that situations that demand high cognitive effort (e.g. via sustained top-down attention) might create anxiety-like interpretation of the bodily signals (Paulus and Stein, 2006; Pollatos et al., 2007) that would be disruptive to the association between presence and interoception, as well as between interoception and performance.

Overall, these findings highlight the importance of considering interoception as an important variable in the evaluation of VR experiences, presence, and body ownership while also informing consumer behavior research towards a better understanding of how we are affected by our bodily feelings and how we interact with the world through our senses (Krishna and Schwarz, 2013).

Managerial implications

Beyond the theoretical contributions, we see two main practical applications of our findings. First, our findings open the door to insights for the creation of VR technologies and contents that can facilitate immersive experiences by integrating external and internal stimulations to induce more realistic emotions and a higher sense of "self" (Tsakiris, 2017). A good example of this would be the development of new integrative and multisensory technologies such as the one created by Riva et al. (2016) called "Sonoception", a device that emits sound and vibration in muscles, stomach area, chest, and head and that can be used during VR experiences to optimize the senses of presence and body ownership by stimulating or simulating the contents of the inner body. Such a device would be the first to try to integrate multisensorial bodily inputs (interoceptive, proprioceptive and vestibular senses) to enhance VR experiences, pushing towards a new wave of VR technologies and experiences.

Second, we also contribute to the development of the field of human-centered user experience research in VR, allowing evaluators and content creators to produce better VR experiences by defining and focusing on what type of experience they are intended to induce. We believe that defining the objectives to be attained in a VR experience by means of emotional, attentional, and performance goals can then help to select how to better tackle presence and body ownership.

For example, our results suggest that in situations of high cognitive effort (e.g., the visual-spatial reasoning game - "DM 1") trying to enhance presence and/or performance via multisensory feedback of inner states might actually create maladaptive perception of the bodily signals and reduce overall VR experience by reducing presence and ownership, and maybe even enhancing the possibility of cybersickness. In contrast, in VR experiences with less cognitive effort and focused on storytelling and free interactivity with the virtual world (e.g., EXP game), inducing attention towards internal bodily signals that could represent one's expectation of emotional reactions might increase overall VR experience and induce positive adaptive experiences instead of negative ones. Finally, in cases in which performance is the goal, then the complexity of the relationship increases, since it is necessary to first evaluate if the performance in the VR experience is sufficiently grounded in the sense of presence (e.g., game DM 2) or not (e.g., game DM 1). Tasks grounded in presence and influenced by interoceptive abilities have been shown in previous studies to be related to intuitive decision-making (Werner et al., 2009; Dunn et al., 2012; Kirk, Downar & Montague, 2011, but see Khalsa et al., 2008 for a conflicting perspective) and psychomotor tasks that demand high attentional focus, such as Olympic shooting (Konttinen, Mets, Lyytinen, & Paaneman, 2003; Konttinen, Lyytinen, & Viitasalo, 1998). If performance is grounded in presence, content creators can then focus on providing accurate multisensorial biofeedback to possibly enhance the user's attentional process to inner sensations and thus influence presence and performance in the task. Thus, understanding such aspects can better inform VR researchers and creators on how to efficiently improve the user's experience in the many existing applications of VR such as in clinical treatment, education, or entertainment.

Limitations and Future Research

Despite our attempt to perform a thorough exploration of the relationship between presence, body ownership, and interoception, we are aware of the limitations of our research. First and foremost, we believe that any attempt to replicate our findings should first take into consideration the sample size. Although our sample (n = 48 for Study 1 and n = 42 for Study 2) provided us with good reliability and it is near to the suggested (n= 44) when taking into consideration the following parameters: F-test, single-factor repeated measures, effect size of .25, and alpha error of .05, power ($1 - \beta$ error prob) of 0.90; a higher sample (at least 10 participants per 1 item) would be necessary to be able to accurately assess the structure of the presence scale (comprising 24 questions in total) and reduce complications with the factor structure and generalization (Costello & Osborne, 2005). Second, the time spent per participant in-lab to test all the variables in this study, approximately 2 hours, along with the fatigue factor in performing the heartbeat tasks, limited us in performing more rounds for both tracking and detection tasks. This limitation is of crucial importance when performing the interoceptive tasks as the number of rounds performed in the tracking and detection task directly affects the reliability of their output values (i.e., accuracy, sensibility, and awareness). Thus, although we performed 40 rounds per participant during the detection task, the minimum suggested by Kleckner et al., (2015) to achieve sufficient reliability, we believe that more rounds are necessary to overcome the challenges of performing the detection task for the first time as well as to enable a better analysis of the area under the ROC curve that represents the accuracy index, since the calculation via detection task only considers a part of the data (i.e., correctly identified synchronous and asynchronous trials). A similar thought goes for tracking tasks, which we believe may provide a more reliable result if at least 12 rounds (instead of 6) are performed.

Therefore, future studies can, for example, not only further investigate these methodological aspects but also test how the simulation versus the real biofeedback of one's cardiac activity might have an impact on presence and body ownership during the same VR experience. In the same sense, future studies can also test how one's cardiac synchronization with musical rhythm, other players, and visual cues may affect different aspects of VR experience; or even how the expectation of one's own cardiac activity versus real activity might have an impact on the perception of difficulty using different levels of game play difficulty. The opportunities in this field are vast and exciting since it is in its youth and it benefits greatly from the current growth of investment in VR technologies.

We are aware that the exploratory nature of our research may also limit the value of our findings. However, the lack of previous studies that have explored the relationship between presence, body ownership, and all three levels of interoception according to the different methods of calculating them (i.e., tracking Vs detection task) made hard for us to go much deeper theoretically without leading to speculations. At this current stage, it is quite improbable to state with certainty the cause-effect of the relationship between presence and interoception or body ownership and interoception. Previous studies (e.g., Aspell et al., 2013; Suzuki et al., 2013) that moderated body ownership illusion using biofeedback did not assess interoception before and after to show if there was any difference in the participants' interoceptive ability. In fact, this would be an intriguing topic for future research, as one tries to modulate body ownership experience and assess if such modulation also have an impact on interoceptive abilities or not.

Conceptually, it might make sense to say that heightened interoceptive abilities would lead to heightened sense of body ownership since heightened interoception has been linked to enhanced emotional experience (Barrett et al., 2004; Wiens, 2005).Moreover, the current perspective on interoception argues that interoceptive signals work alongside with sensorial (exteroceptive signals) as way to provide the brain with signals to predict the future state of the organism. This theory is called active interoceptive inference (Seth, 2013) and it proposes that subjective feeling states (including the experience of body ownership) arise from interoceptive predictions and thus are modulated the multisensory integration of both interoceptive and exteroceptive signals.

However, Demartini et al., (2016) have also shown that differences in interoception (accuracy) between patients with functional neurological disorders and healthy control group does not reflect on differences in body ownership, either via self-report or proprioceptive drift. Thus, the exploratory nature of our study was relevant to provide evidence that even if the causal-effect of the relationship is indeed in accordance with the active interoceptive inference theory, the association between interoception and body ownership (and presence) may not be so straightforward, depending on multiple factors including level of interoception, interoceptive method used, and even characteristics of the stimuli (i.e., type of game and first person perspective or not).

The current research adds to the still fairly recent topic of integrative multisensorial information and bodily feelings (for a review see Herbert & Pollatos, 2012; Schwarz & Clore, 2007; Craig, 2009) in consumer behavior research (for a review see Krishna &

Schwarz, 2014). We believe that the continuing convergence of consumer behavior research with other disciplines such as neuroscience will push us to a better understanding of the diverse aspects involving embodiment cognition as well as other well-stablished psychological theories used in our field. Thus, understanding how the sensation from internal bodily activities (i.e., interoception) influences our perception of being present in a virtual environment and of owning a virtual body might lead us to the possibility of integrating internal and external stimuli to generate realistic experiences in VR and, thus, to the development of what can be the next generation of Virtual Reality experiences.

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Appendix A: Measures

Presence measurement scale (Witmer & Singer, 1998)

Question: Characterize your experience in the environment, by marking an "X" in the appropriate box of the 7-point scale, in accordance with the question content and descriptive labels. Please consider the entire scale when making your responses, as the intermediate levels may apply. Answer the questions independently in the order that they appear. Do not skip questions or return to a previous question to change your answer.

WITH REGARD TO THE EXPERIENCED ENVIRONMENT

1. How much were you able to control events?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

2. How responsive was the environment to actions that you initiated (or perfo

|________|________|________|________|________|________|________|
NOT RESPONSIVE MODERATELY RESPONSIVE COMPLETELY RESPONSIVE

3. How natural did your interactions with the environment seem?

|________|________|________|________|________|________|________|
EXTREMELY ARTIFICIAL BORDERLINE COMPLETELY NATURAL

4. How much did the visual aspects of the environment involve you?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

5. How natural was the mechanism which controlled movement through the environment?

|________|________|________|________|________|________|________|
EXTREMELY ARTIFICIAL BORDERLINE COMPLETELY NATURAL

6. How compelling was your sense of objects moving through space?

|________|________|________|________|________|________|________|

NOT AT ALL	MODERATELY COMPELLING	VERY COMPELLING

7. How much did your experiences in the virtual environment seem consistent with your real world experiences?

|________|________|________|________|________|________|________|

NOT CONSISTENT	MODERATELY CONSISTENT	VERY CONSISTENT

8. Were you able to anticipate what would happen next in response to the actions that you performed?

|________|________|________|________|________|________|________|

NOT AT ALL	SOMEWHAT	COMPLETELY

9. How completely were you able to actively survey or search the environment using vision?

|________|________|________|________|________|________|________|

NOT AT ALL	SOMEWHAT	COMPLETELY

10. How compelling was your sense of moving around inside the virtual environment?

|________|________|________|________|________|________|________|

NOT COMPELLING	MODERATELY COMPELLING	VERY COMPELLING

11. How closely were you able to examine objects?

|________|________|________|________|________|________|________|

NOT AT ALL	PRETTY CLOSELY	VERY CLOSELY

12. How well could you examine objects from multiple viewpoints?

|________|________|________|________|________|________|________|

NOT AT ALL	SOMEWHAT	EXTENSIVELY

13. How involved were you in the virtual environment experience?

|________|________|________|________|________|________|________|

NOT INVOLVED	MILDLY INVOLVED	COMPLETELY ENGROSSED

14. How much delay did you experience between your actions and expected outcomes?

|________|________|________|________|________|________|________|

NO DELAYS	MODERATE DELAYS	LONG DELAYS

15. How quickly did you adjust to the virtual environment experience?

|________|________|________|________|________|________|________|

NOT AT ALL	SLOWLY	LESS THAN ONE MINUTE

16. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

|________|________|________|________|________|________|________|

NOT PROFICIENT	REASONABLY PROFICIENT	VERY PROFICIENT

17. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

|________|________|________|________|________|________|________|

NOT AT ALL	INTERFERED SOMEWHAT	PREVENTED TASK PERFORMANCE

18. How much did the control devices interfere with the performance of assigned tasks or with other activities?

|________|________|________|________|________|________|________|

NOT AT ALL	INTERFERED SOMEWHAT	INTERFERED GREATLY

19. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

|________|________|________|________|________|________|________|

NOT AT ALL	SOMEWHAT	COMPLETELY

IF THE VIRTUAL ENVIRONMENT INCLUDED SOUNDS:

20. How much did the auditory aspects of the environment involve you?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

21. How well could you identify sounds?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

22. How well could you localize sounds?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

IF THE VIRTUAL ENVIRONMENT INCLUDED HAPTIC (SENSE OF TOUCH):

23. How well could you actively survey or search the virtual environment using touch?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

24. How well could you move or manipulate objects in the virtual environment?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT EXTENSIVELY

Scoring :

Total : Items 1 to 19 (reverse items 14, 17, 18)

- « Realism » : Items 3 + 4 + 5 + 6 + 7 + 10 + 13
- « Possibility to act » : Items 1 + 2 + 8 + 9
- « Quality of interface » : Items (all reversed) 14 + 17 + 18
- « Possibility to examine » : Items 11 + 12 + 19
- « Self-evaluation of performance » : Items 15 + 16
- « Sounds* » : Items 20 + 21 + 22
- « Haptic* » : Items 23 + 24

Body Ownership – based on Suzuki et al. (2013) and Aspell et al. (2013)

Ownership: focused on assessing the subjective experience of body ownership

1. It felt as if the virtual body was my body

3. It seemed as if I was feeling the location where the virtual body was

Control: serving as control questions to provide equivalent attentional demands without specifically relate to body ownership

2. It seemed as if I had more than one body

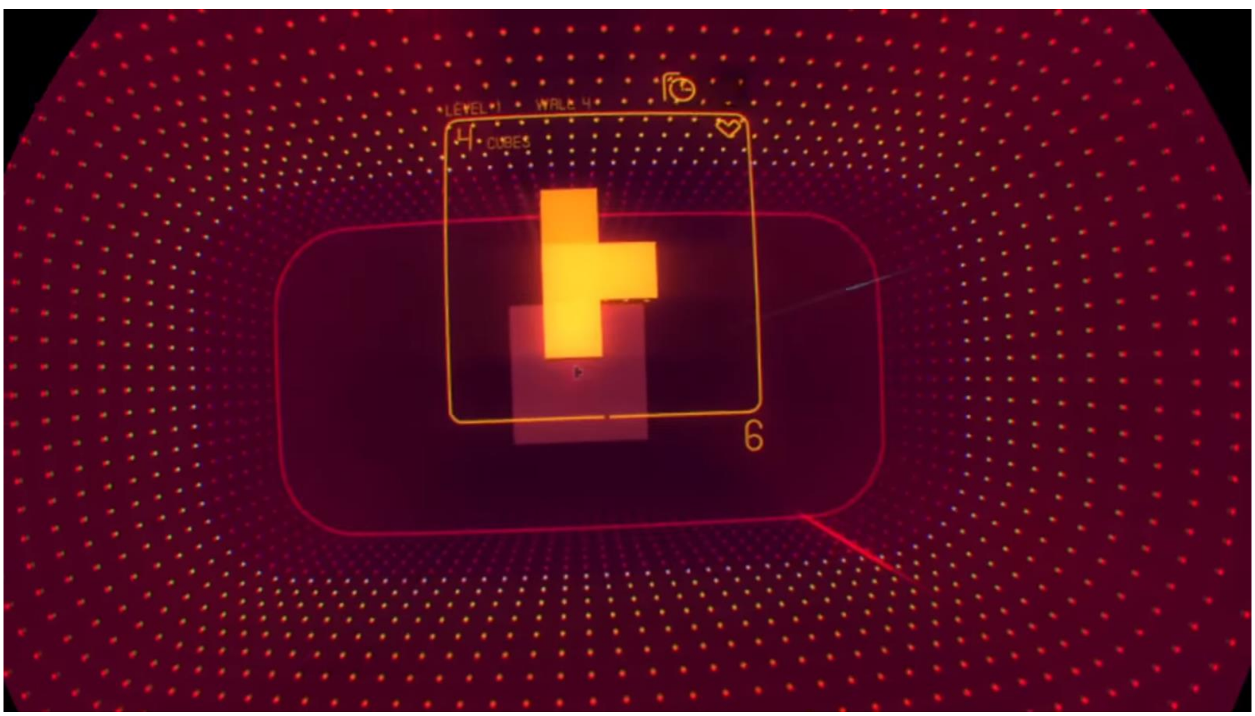
4. It felt as if I no longer had a body, as if my body had disappeared.

Scale: All responses were collected using a 7-point continuous visual scale with - 3 representing "strongly disagree" and + 3 "strongly agree", thus, allowing participants to select intermediate points across the scale.

Appendix B: Conditions

STUDY 1 and 2 - Experiential condition: London Heist game

STUDY 1 and 2 - Decision-making condition 1: Super-hyper cube game



STUDY 2 only - Decision-making condition 2: MLB The Show 18 (practice batting mode)