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Is there Proprioceptive Comfort?

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Sensory comfort, the idea that certain stimuli lead to positive feelings (e.g., calmness, relief, joy), has been well established for 'external' senses like vision and audition. However, despite 'internal' senses such as proprioception, the sense behind one's body position and movement, being well studied, their respective sensory comfort (and perhaps the lack of) has been virtually unexplored. Here, previous work related to the potential of proprioceptive comfort is reviewed to provide context as to whether proprioceptive comfort truly exists. From the basis of sensory comfort provided by body movement, pain relief, proprioceptive art, and their relationships with proprioception, the argument is made that proprioceptive comfort does exist. This opens the door for research expanding on its characteristics and having major implications for supplementing and revitalizing proprioceptive comfort in individuals with impaired proprioception.

Keywords: sensory comfort, sensory pleasantness, proprioception, proprioceptive comfort

Sensory comfort is the idea that certain sensory stimuli lead to positive feelings, including calmness, relief, or joy. Although there is no direct definition for sensory comfort, comfort has been defined (referencing tactile comfort) as a psycho-physio-physical state of neutrality with no pain or discomfort (Hatch, 1993; Kamalha et al., 2013; Slater, 1977). Various terminology is used when referring to this idea (pleasure, aesthetics, preference, sensitivity, etc.); however, throughout this paper, the term 'comfort' will be used predominantly.

Sensory comfort based on external stimuli (i.e., viewing, hearing, smelling, tasting, touching, etc., something around us) is relatively well studied (Gallace & Spence, 2011; Kringelbach, 2015; Markovic et al., 2007; Tiihonen et al., 2017). Most people can also easily pinpoint pleasurable aspects of those specific senses (e.g., calming music, soft blanket). However, sensory comfort becomes less clear when framing it around internal stimuli. For example, many people experience comfort from yoga or dancing without major external stimulation. Often, these activities involve an internal sense called proprioception, the internal awareness of one's body position and movement (Héroux et al., 2022; Marasco & Nooij, 2023; Moon et al., 2021). Proprioception is well established as a bodily sense within the literature; however, proprioceptive comfort (or potentially the lack thereof) is relatively unexplored. This paper aims to explore the question of proprioceptive comfort in humans and whether it truly exists in depth.

Comfort from Body Movement

From many anecdotal experiences, it's clear that body movement, whether running, swimming, yoga, or dancing, can be rather cathartic. Exercise has been shown to increase central monoamine levels of endorphins, norepinephrine, dopamine, and serotonin, improving individuals' moods (Alizadeh Pahlavani, 2024). The production of these 'happy' neurotransmitters could be the end of the story; however, could this also be a neurological response to proprioceptive comfort? Linking muscle movement with a happier (and more comfortable) mood can provide insight into a possible proprioceptive comfort mechanism. Endorphins and irisin may be the key. Endorphins can reduce pain specifically caused by muscle contraction. In contrast, irisin, released from muscles during exercise, has been shown to impact central monoamine levels and directly links muscles and the brain (Alizadeh Pahlavani, 2024).

Proprioception is an aesthetic sense based on the proprioceptive pleasure and comfort from viewing and participating in movement (Cole & Montero, 2006; Montero, 2006). The perfect example is dance because, at its core, dancing creates beauty in movement (Cole & Montero, 2006; Montero,

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2006). As Montero (2006) pointed out, if you ask a dancer why they move in specific ways, often the answer is because it is more graceful or aesthetically pleasing. Further, there is an important distinction in that when learning dance, vision is critical because the dancer relies on how their movement looks, whereas when dancing, proprioception is crucial because they must rely on how the movement feels. Through their proprioception, dancers can utilize visual imagery, but ultimately, proprioception is their main cue (Montero, 2006). Montero (2006) further pointed out that there are very skillful blind dancers, such as Alicia Alonso, who must rely primarily on proprioception while learning as well as performing their craft. This suggests that in the absence of vision, proprioceptive cues are sufficient to create an aesthetic and enjoyable experience for the dancer.

Outside of dancing, Montero (2006) posed that mirror neurons could serve as a potential mechanistic explanation behind perceiving proprioceptive comfort from simply watching others dance. Mirror neurons fire the same way when someone performs an action or watches someone else perform the same action (Rizzolatti et al., 1996). Spectators could be viewing the aesthetically beautiful movements, and their bodies would be sympathetic toward the graceful and calming motion as if it were their own. This extends beyond dance and can help explain why, for example, you can also gain a sense of relief when someone next to you cracks their back after a long day.

Similarly, yoga is an activity that many people find relaxing and can potentially provide proprioceptive comfort. A big component of yoga is controlled breathing, which increases proprioceptive awareness and provides a relatively immediate sense of calm. Further, controlled breathing can increase calming hormones like prolactin and oxytocin (Schmalzl & Sullivan, 2022). Over time, meditation practices like yoga have been shown to cause structural and functional changes in the somatosensory cortex and insula, both of which are part of the proprioceptive pathway (Schmalzl & Sullivan, 2022). Static stretching and conscious slower breathing have also increased parasympathetic activity and reduced stress (Sakurai et al., 2024). These findings suggest that utilizing muscles in calming manners through activities like yoga and stretching not only provides comfort but involves similar pathways as proprioception, hinting that they may provide specifically proprioceptive comfort. Although not immediately thought of as a proprioceptive activity, breathing does enhance proprioceptive awareness, which, at the very least, links the two with comfort and relaxation.

Assessing the impact of body movement on those without proprioception could help further elucidate if movement and exercise provide proprioceptive comfort. One example is from Ian Waterman, who lost his ability to move and his sense of proprioception and touch as a teenager. Although he relearned how to move utilizing visual input, he has shared that he does not have the same enjoyment from moving without proprioceptive and tactile sensations. Further, he seeks out deer to watch their graceful movements to enjoy proprioception visually (Cole & Montero, 2006; Tuthill & Azim, 2018). Other individuals with quadriplegia share similar sentiments in that there is no real substitute for the joy of being able to move and use your body physically (Cole & Montero, 2006). These anecdotes suggest that movement without proprioception is far less enjoyable, and mirror neurons may not be sufficient to produce comfort without an intact proprioceptive sense. This points to proprioception having a distinct role in providing comfort during movement and the possibility of a positive relationship between proprioceptive comfort and proprioceptive sensitivity. Perhaps those with impaired proprioception, such as older adults and individuals with a history of stroke (Henry & Baudry, 2019; Rand, 2018), have reduced proprioceptive comfort as a result.

Proprioceptive Role in Reducing Pain and Stress

In a literal sense, pain reduction provides a sense of objective comfort. Interestingly, proprioception is likely behind modern and innovative pain reduction methods. Techniques like transcutaneous electrical nerve stimulation, intramuscular stimulation, and spinal cord stimulation may sound like torture, but are methods of pain relief (Prochazka, 2021). The science behind the relief is primarily the Gate Theory of Pain, which states that intense sensory activation can inhibit the nociceptive (pain) signals from reaching the brain and thus create pain relief (Prochazka, 2021). Proprioception is involved because muscle spindles and Golgi tendon organs (GTOs), two primary proprioceptors (specialized sensory organs (Tuthill & Azim, 2018)), have the lowest thresholds to electrical stimulation. This means that spindles and GTOs are activated from stimulation quicker than other nerve fibers (most importantly, nociceptive fibers), suggesting that their proprioceptive input is behind the pain relief experienced from the above-mentioned stimulation techniques (Prochazka, 2021). A simple example of this in action was provided by Prochazka (2021) in that if you hit your thumb with a hammer, a common response would be to shake your hand back and forth. The 'stimulation' would be the hand shaking, which would send proprioceptive signals to the spinal cord (and the ascending pathway that follows (Ager et al., 2017)) before the nociceptive signals are sent, effectively inhibiting or reducing the pain response.

Proprioceptive feedback could also play a critical role in trauma therapy. A practice called Somatic Experiencing® utilizes attention to proprioception, interoception, and kinesthesia and has been shown to relieve patients' chronic and traumatic stress (Payne et al., 2015). The sympathetic (arousing) and parasympathetic (calming) nervous systems have a homeostatic relationship that requires balance. If this balance becomes impaired and, for example, shifts into a

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sympathetic-dominant state, it can lead to harmful emotional and physiological stress (Payne et al., 2015). Sympathetic 'fight, flight, or freeze' activation results in faster breathing and heart rate to push greater amounts of oxygen and blood to areas that may need it, among other physiological changes. In contrast, parasympathetic 'rest and digest' activation results in a slower heart rate and muscle relaxation, among other changes, which help relieve stress and can provide comfort (Gellhorn, 1964; Payne et al., 2015).

Payne et al. (2015) pointed out that muscle activation can be limited in a sympathetic state as certain trauma responses are to completely freeze in place (e.g., tonic immobility) and dissociate. One may appear stressed from an outside perspective with indicators such as shaking, trembling, or postural changes. Payne et al. (2015) described these movements as releasing excess sympathetic activation. Movements like trembling, specifically involved with tonic immobility, may serve as the body's attempt to warm necessary muscles to prepare for a sympathetic defensive response (Payne et al., 2015). The thought is this could release the body from the frozen state and kick-start the cyclic balance that will facilitate parasympathetic activation (Payne et al., 2015).

In individuals who are in a sympathetic-dominant state, proprioceptive feedback from manual muscle activity can help communicate to the body that sympathetic arousal is unnecessary and trigger parasympathetic activation, resulting in stress reduction (Gellhorn, 1964; Payne et al., 2015). Similarly, in an experiment where rats were exposed to stressful environments via an inescapable shock, allowing them to fight each other reduced their adrenocorticotropic (stress) hormone levels compared to controls (Payne et al., 2015; Weinberg et al., 1980). These examples suggest that (in)voluntary muscle movement can serve as a proprioceptive outlet to reduce stress and ultimately create a more comfortable existence.

Proprioceptive Art

People typically perceive art as a visual or auditory experience; however, there has recently been interest in proprioceptive art. Although this may take a multisensory approach, proprioceptive art has been defined as art that would lose some meaning without proprioception (Spence, 2022). This makes it distinctly reliant on the proprioceptive sense. Carsten Höller, a Belgian-born German artist, is perhaps one of the best-known artists that purposefully incorporates proprioception into their work (Spence, 2022). Höller brought an 'Experience Exhibition' to New York in 2011, which included art that broke many individuals' perceptions of what art truly is. His exhibition included an entire room made to look upside down, a water tank where people could float weightlessly, and a mirrored carousel that people could ride that slowly spun in one direction, while the center column rotated in the opposite direction (Spence, 2022). His art is focused on distorting typical perception, forcing many viewers to rely on their own body's spatial awareness (i.e., proprioception). Proprioceptive art distorts the traditional view of art in a unique yet enjoyable way.

Interestingly, proprioceptive art has trickled into the research world as well. One of Höller's works, *The Pinocchio Effect* (1995), created a vibratory experience leading to an illusory perception of one's nose growing (Spence, 2022). This led to the Pinocchio illusion (and arm extension illusion) that researchers have used to examine proprioceptive manipulation (Burrack & Brugger, 2005; Michael & Park, 2016; Morris, 2020; Morris et al., 2024). Certain muscle vibrations can create proprioceptive illusions by utilizing proprioceptors and other mechanoreceptors (sensory neurons) such as Pacinian corpuscles (vibration sensors (Marasco & Nooij, 2023; Roudaut et al., 2012)). When perceived, these illusions spark a lot of joy in participants simply due to the unique experience of perceiving your nose growing when you're cognitively aware of the impossibility. Notably, these illusions specifically target proprioception and are perhaps one of the few possible examples of unisensory proprioceptive comfort. Typically, when eliciting proprioceptive illusions, participants are asked to wear a blindfold or close their eyes to eliminate the impact of visual cues (Burrack & Brugger, 2005; Michael & Park, 2016; Morris, 2020; Morris et al., 2024).

Conclusion

Sensory comfort is almost always multisensory, at least in a real-world setting. For example, a hike through nature could provide sensory comfort in many external forms (e.g., smelling fresh air, viewing beautiful landscapes, and hearing birds chirping) and internal (e.g., the hiking/movement itself). One reason internal sensory comfort may not be considered as readily is that it is much more challenging to separate it than one's external senses. If researchers seek to investigate visual comfort, they may place a participant in front of a computer screen and ask them to select their preferred visual stimuli. From there, researchers can dive into the specific features of preferred versus non-preferred stimuli. This formulaic structure isn't possible for proprioceptive comfort. Researchers cannot ask participants which 'version' of proprioception they prefer. However, they can ask about different proprioceptive activities, such as dancing, yoga, or therapeutic techniques. Learning from individuals with impaired proprioception, such as Ian Waterman, researchers can start to reveal the important role of proprioception in inducing proprioceptive comfort. This can be further expanded by examining the relationship between proprioceptive sensitivity and proprioceptive comfort in the general population.

It can be asserted that the potential for proprioceptive comfort derived from exercise is solely a chemical interaction distinct from sensory comfort. Other forms of potential propri-

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oceptive comfort are multisensory, and the perceived comfort could result from an external, rather than proprioceptive, sense. However, proprioceptive comfort may be far more complicated than external sensory comfort. To return to the definition of sensory comfort: "the idea that certain stimuli lead to positive feelings, including calmness, relief, or joy […] a psycho-physio-physical state of neutrality with no pain or discomfort." The defined comfort that body movements, therapies, and proprioceptive art can provide in a proprioceptive domain provides ample evidence for proprioceptive comfort. Further, several potential mechanisms exist behind proprioceptive comfort with various neurotransmitters and common pathways. Both the tactile and proprioceptive senses utilize the medial lemniscus-dorsal column and the same mechanoreceptors (Ager et al., 2017; Roudaut et al., 2012). Once tactile comfort mechanisms are further elucidated, they could be a strong stepping-stone toward revealing the mechanisms underlying proprioceptive comfort.

There is much more to explore in this domain, as is there with comfort from other external senses. Future research should explore comfort in models that account for individual differences in how people perceive proprioceptive comfort and allow for comparisons between intact, impaired, and removed proprioception. With those comparisons, the question of proprioceptive comfort can start to be definitively answered, and its benefits and applications can be effectively explored. This could provide valuable insights into using novel physiotherapeutic techniques and further understanding how to supplement and revitalize proprioceptive comfort to improve the quality of life in individuals with impaired proprioception.

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