Understanding the Link Between Virtual Reality Immersion and Sensory Integration: Recognizing Opportunity- and Risk Potential for School-Age Users, and How to Address Them

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Sensory integration is central to perceptual processing of real-world stimuli, and thus to understanding how virtual reality (VR) "tricks" the senses. Based on literature review and expert-interviews, we discussed (1) how sensory functions relate to body self-image, (2) how sensory experiences affect identity-development, and (3) what opportunities and risks VR-immersion presents for schoolchildren. Results strongly advise VR-users' development-age should be considered before VR-immersion, to minimize development-disruption potential. This mandates, (i) age-appropriate VR-software selection, based on immersion-criteria descriptors, and (ii) application of detailed use-recommendations, including sensory-intervention strategies. Both, descriptors and use-recommendations are introduced here, and support safe VR-use with schoolchildren.

Keywords: virtual reality immersion, VR and schoolchildren, VR in education, child development, identity development, sensory integration, sensory perception, disembodiment, VR use recommendations, sensory intervention strategies, VR app descriptors, VR risk potential

INTRODUCTION

This study sets out to describe the connections between virtual reality (VR) and sensory integration (SI), where VR is a young, subject-specific technology, and SI is a subject-specific topic in child development, special education and ergotherapy. In short, VR induces, via computer-generated sensory stimuli, perceptions that closely resemble actual physical reality, while SI interprets perceived sensory stimuli, regardless of their origin, to ultimately generate motoric responses to perceived environments. The specifics of these processes are described here.

Introducing Virtual Reality and Immersion

Market analysts have for some time predicted an increasing future market for immersive technologies, such as VR (Mordor Intelligence Industry reports, 2023), with a projected 56.8% growth during 2024-2029 (Tenzer, 2023). Thus, immersive technologies will also increasingly be employed in education, especially since newer, more affordable VR-technologies are now widely available. For example, in Germany, North

Rhine-Westphalia's ministry of education reported the purchase of 3000 VR-headsets for educational institutions during the previous three years (Schulministerium nrw, 2024). Immersion refers specifically to "immersion in a virtual environment" (Duden, 2023), and is defined as "the degree to which a range of sensory channels is engaged by the virtual simulation" (Kim & Biocca, 2018, pp. 94–102). Especially the technology of VR-headsets creates a very high degree of immersion, and this study consequently focussed on complete VR-experiences provided through the use of VR-headsets.

Virtual reality is defined as computer-generated reality, comprised of computer-generated images (3D) and sound (Bendel, 2023). Computer programs that create specific VR environments and experiences for VR-use are known as VR-applications (VR-apps); their primary goal is to immerse the user in VR. The subjective aspect of the VR-immersion experience is also referred to as presence, defined as "one's sense of being in the virtual world" (Berkman & Akan, 2019, pp. 1–10). During presence, the physical reality recedes in favor of VR, and returning to physical reality after immersion is often difficult (Bendel, 2023). The immersion experience can be both enriching and disturbing; enriching, because it affords users certain experiences not otherwise accessible to them in the real world, and disturbing because during immersion a user's brain must cope with unfamiliar, somewhat incongruous and often contradictory sets of sensory stimuli. Thus VR-experiences create opportunities and challenges for users (Bendel, 2023). Addressing these opportunities and potential risks is especially important for educational institutions using/planning to use immersive media with schoolchildren, as it is these institutions' responsibility to foster learners' humanism (Maples, 1979) and protect their mental-, emotional- and physical well-being. After all, humanistic education emphasizes a learner's self-actualization through holistic development (including personal-, social-, moral-, as well as academic development). This applies equally, if not more (as it might be more difficult to achieve), to physically challenged and/or neurodiverse learners, particularly in inclusive learning environments.

Introducing Sensory Integration

The human perceptual system is based on the integration of sensory stimuli, whether generated by the actual physical environment or else computer-generated, and can be challenged by bridging the gap between immersion and physical reality (Ayres et al., 2002; Kesper & Hottinger, 2002). Sensory integration is defined as the sorting and combining, in the brain, of all sensory information received by a person's sensory organs (Ayres et al., 2002), for the purpose of engaging with the environment in a meaningful (goal-oriented) way. SI is also known as "central processing", as it is the process of the central nervous system translating sensory stimuli into action (Ayres et al., 2002). As such, a person's behavior, that is, their interaction with the environment, is closely linked with their sensory system. The sensory system can be categorized based on stimuli origin (Hübner et al., 2020) into exteroception, proprioception, and interoception. Exteroception refers to the processing of sensory stimuli received from outside the body (distance-senses); these include vision, hearing, tasting, smelling, and heat-perception. Proprioception refers to the processing of sensory stimuli received from moving body parts within one's body (e.g., from muscle- and likely fascial tissue); they are also referred to as "base-senses", and inform about kinesthetic changes within and, ultimately, the spatial positioning of one's body in the physical environment. Lastly, interoception refers to the processing of sensory stimuli received from one's own internal organs; these also are included in "base-senses", as they inform about the internal, physical state of one's body. The overarching concept of neuroception describes the subconscious processing of sensory stimuli received from any of the above-mentioned senses, for the rapid assessment of one's physical environment (e.g., to rapidly recognize danger) (Hübner et al., 2020). People's visual sense is generally considered dominant over other senses (Hetzer & Arbinger, 1995). There are parallels between SI-dysfunctions and VR, as both present challenges to effective SI, due to incongruent sensory stimuli being received by the brain, or else the brain not being able to effectively interpret complex sensory information. These parallels suggest SI-intervention strategies might be effectively applied with VR-users, especially when they return from an immersive-virtual experience with its sensory illusions, back to a physical reality with its real-world stimuli. This so-called transitional competence develops from high-quality (that is, real-world stimuli) body sensory perception and its subsequent SI. Here, SI-intervention would facilitate the restoration of a familiar sensory order (Merleau-Ponty et al., 2003; Sacks, 1991; Schmitt, 2002; Slater & Sanchez-Vives, 2014; Tajadura-Jiménez et al., 2017). Irregularities in behaviour (e.g., learning disorders) may thus be mitigated via SI intervention, and conversely, irregularities in SI (i.e., SI dysfunction) may be mitigated via behavioral intervention. Ergotherapy and similar SI intervention-strategies commonly employ these interventions as therapeutic tools in special education. As VR is considered to have future potential for the school setting, the education system needs competent teachers for the healthy use of VR (Focus, 2023; Holly et al., 2021; Jabbar & et al, 2021; Mulders et al., 2023; Zielinski, 2019). But VR must be applied with care to avoid risks potentially arising from disembodiment during VR-use (Horowitz & Maes, 2025).

Working with children of developmental age in a pedagogical setting carries exceptional responsibility and thus requires great caution, especially during times of rapid technological advancement and when integrating new technologies into the classroom setting. Thus, identifying and recognizing potential risks inherent in VR-use with schoolchildren was an object of this study. Ultimately, this study attempts to guide the development of expertise in VR-utilization with schoolchildren, by helping to realize VR's potential for enriching the education sector, while minimizing potential risks to users of developmental age. VR content that provides good qualitative interaction options offers opportunities for participation and physical self-efficacy experiences for people with physical or health limitations, who are unable to experience some spaces in the physical environment (Moon & Han, 2022; Stendal et al., 2011). However, digital spaces need an inclusive technology design (Hine, 2025). These opportunities should be safe to use for children and young people. We are not aware of any study having previously attempted this.

STUDY DESIGN

This study attempted to answer the central research question:

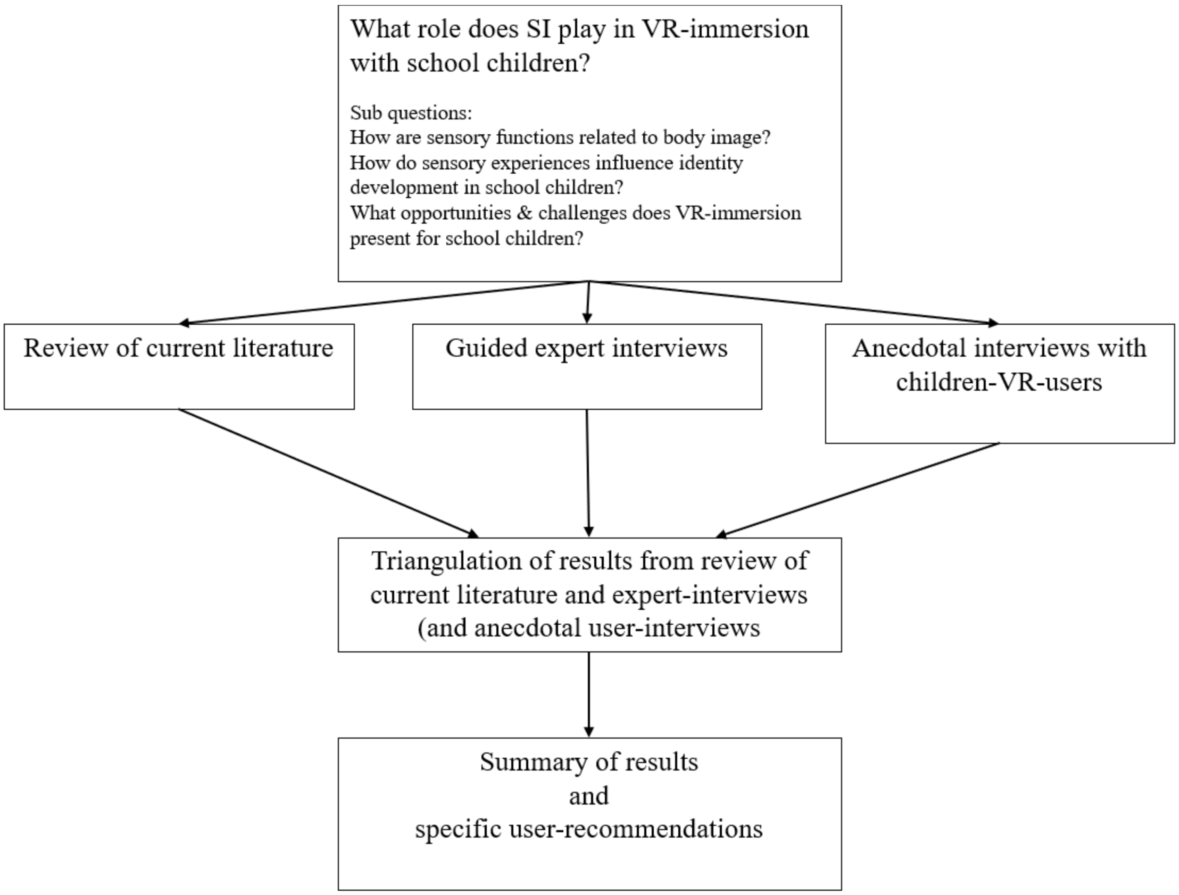
"What is the role of sensory integration (SI) in VR-immersion with schoolchildren?"

To guide the process, the following sub-questions were devised:

1. *How are sensory functions related to body self-image?*
2. *How do sensory experiences influence identity-development in schoolchildren?*
3. *What opportunities & risks does VR-immersion present for schoolchildren?*

Research sub-questions 1 and 2 were addressed via review of relevant current literature. Research sub-question 3 was addressed via guided expert-interviews. Figure 1 provides an overview of study design.

FIGURE 1
OVERVIEW OF STUDY DESIGN, INCORPORATING A REVIEW OF RELEVANT; CURRENT LITERATURE, AS WELL AS GUIDED EXPERT-INTERVIEWS



Source Author

LITERATURE REVIEW

Literature Review Method

To answer how sensory functions relate to self-image, and how sensory experiences affect identity-development in schoolchildren, extensive review of current relevant literature was conducted. The main search was carried out between November 2022 and March 2023, via U: Search (University of Vienna), Science Direct (FH Campus Wien), ResearchGate (online) and utb e-library (PH NOE). Search terms included *sensory integration, virtual reality, children, disembodiment, sensorimotor embodiment, identity, immersion, vestibular functions, perception, embodied cognition* and *bodily self-identification*, and German terms *Medialität, Realitätsbewusstsein* (*mediality awareness and reference to reality)*, searched via Pedocs (Pedocs, 2025). Additionally, the Journal of Child-Computer-Interaction was scanned directly for the terms, *immersion and children*, and *embodiment*. The search terms *virtual reality, motion sickness*, and *perception* by themselves identified an unmanageably large number of publications, which warranted combining search terms. After initial identification, the following exclusion criteria were applied: duplicates; study too old (< 2010), reference to outdated technology (such as wired systems); too technology-specific; studies with thematic overlaps, on unrelated age-group, or else with few citations; and publications in languages other than English or German. Lastly, included studies' citations also were scanned for additional publications. Thus, our findings were extracted from full texts of publications with high topicality; younger than 2020 (unless representing standard-works); relating to school setting/school-age; containing findings about SI that establish connections to the immersion effect and provide indications for further research into increased sensory-functional VR-tolerance. Research published after our main literature review (2023-current) was also included, if it related to childhood and VR-use, with practical suggestions and relevant recommendations for VR-use of the stand-alone VR-technology devices, e.g. Quest II (Meta, 2023).

Literature Review Findings

Sensory Functions in Relation to Body Self-Image and Identity Development in School Children

The VR-immersive experience in general is based on *tricking the senses*. In the concept of SI, senses are supported by the *basic body senses* (Ayres et al., 2002), which in turn provide the foundation for body orientation and movement planning (Kesper & Hottinger, 2002). Perceiving oneself as being immersed into a virtual world relies on the immersion-effect, which is brought on by a user's brain interpreting the computer-generated visual stimuli from VR as real-world stimuli, because the brain is used to being presented with the familiar, actual physical environment (i.e., not questioning the origin of visual stimuli). Part of the immersion experience is the feeling of "disembodiment" (literally: the state of being "divested of a body, of corporeal existence, or of reality"; Merriam-Webster, 2023) - which describes being transported out of one's own body perception and into a virtual environment. Disembodiment during immersion occurs because VR only engages the visual and auditory senses, while all other body-senses continue to receive stimuli from the actual physical reality (e.g., tactile, vestibular, ...). However, as the brain's attention focus during VR-use is on VR-generated visual and auditory stimuli, the user consequently interprets VR-generated stimuli as "real", and ignores the rest of the body, with it's additional, yet incongruent, sensory information; *disembodiment* ensues. Changes in one's body perception (or else "body sense", or "sixth sense"), such as disembodiment, are important indicators for understanding how a user's sensory system attempts to adapt during immersion, and generally how the immersion effect arises (Ayres et al., 2002).

The synchronicity of visuo-tactile and the visuo-vestibular perception improves body perception (Preuss Mattsson et al., 2022). For example, the "rubber-hand illusion", that is, the sensory incorporation of a rubber hand into one's own body representation, is the result of irritations of the sensory control circuits (Della Longa et al., 2021), and demonstrates the relativity of body perception (Tieri et al., 2015). One's own body-representation and internalization of one's body-image in body-illusion experiments influence one's range of perception (Tajadura-Jiménez et al., 2017). A distorted body image can be attributed to a faulty classification of kinesthetic (that is, originating from the muscles) or tactile (that is, originating from the skin) stimuli (Frostig, 1992; Renaux et al., 2022; Van Hecke et al., 2021). Inner, visceral signals, as well as visuo-tactile, cardio-visual and vestibular stimulations have a general effect on body self-image, SI, cognitive stimulus selection, and the perception of touch, pain and self (Aspell et al., 2009; Azzalini et al., 2019; Ho et al., 2023; Lenggenhager & Lopez, 2015; Macauda et al., 2015; Pratviel et al., 2022; Salomon et al., 2013). Full-body illusions experienced in VR affect one's body self-image and physiological responses such as body temperature, brain waves, and heart rate (Salomon et al., 2013; Schöne et al., 2023). The basic senses, and proprioception in particular, influence torso stability, which can have an impact on VR tolerance (Vega & Cobo, 2021). The level of perceived disembodiment itself is very individual and body specific (Schroeder et al., 2023).

Sensorimotor capacities strongly influence body-identity, learning and perception abilities, and environmental interaction (Ntoumanis et al., 2022; Tsakiris, 2010). Proprioception is directly linked to the tactile and vestibular senses, and is the foundation of body self- image, muscle tone, and positioning in space. Embodiment serves in identity development in a complex, individual and predictive sensorimotor process of differentiation of self from environment (Longo et al., 2008; Marotta et al., 2016; Myin & Zahnoun, 2018; Rochat, 1998). Real-world environmental experiences, accompanied by movement, during concrete-operational development are thus essential for the formation of a child's identity and of constructive learning processes (Brinkmann, 2019; Seitz, 2000; Xu & Zhang, 2022). The body sensory system can promote the ego-perception of the self through full-body, simultaneous environmental interaction (Ciaunica et al., 2022). Self-confidence and body self-image are impacted by multisensory stimulation (Farmer et al., 2014). There are clear indications for the possibility of manipulating humans through visually created reality (Dörner et al., 2019), and thus one's identity-concept might be influenced by immersive VR (Slater & Sanchez-Vives, 2014; Tajadura-Jiménez et al., 2017).

VR-users identification with a virtual body is measurable via EEG in the cortex, the same brain-region generally associated with body self-awareness and self-identity (Aspell et al., 2012; Thirioux et al., 2016). Connections between identity, self-awareness and body sensory processing were also demonstrated through psychiatric and neurological studies on illusory self-perception (Gyllensten et al., 2010; Heydrich et al., 2013). Motor action planning and cognitive performance, but also VR-immersion tolerance, are all linked to the vestibular system (Renaux et al., 2022). Well-organized SI helps the brain correctly adapt to sensory stimuli, thus sensory perceptions can be compared to brain food that *supports sensory digestion* (Eggert, 2008). A well-developed body perception increases SI flexibility (Maselli et al., 2016; van Beers et al., 2002), that is SI can more accurately (and faster) interpret, and subsequently react to, contradictory sensory stimuli. The function of the mental system is not yet entirely understood; however, information can enter the brain even without conscious perception (Kandel, 2018); these so-called subliminal messages contain the risk of subconsciously influencing behavior (Shaw, 2016). The theory of embodied predictive coding assumes the processing of our sensory perceptions is based on the brain's internal model of the environment (Schmitt, 2002). The frontal lobe of the brain, and especially the prefrontal cortex, is thought to play an important role in this processing of sensory stimuli. The development of an individual's prefrontal cortex continues into young adulthood, and is linked to physical activity (Walk & Evers, 2013).

So called "critical incidents", such as headaches, dizziness, or nausea, experienced by VR-users during immersion are indicators for sensory overload due to the immersion effect (Bezmalinovic, 2022; Fisher et al., 1991). The occurrence of such symptoms in this context is also referred to as cybersickness, which results from a discrepancy between a user's perceived sensory information received from the eyes and that received from the balance (or vestibular-) system in the inner ear (Bezmalinovic, 2022; Fisher et al., 1991). It could be shown, that an impaired vestibular system may cause dizziness and an out-of-the-body-experience, which also sometimes comes with neurological or psychological factors, e.g. depersonalization (Lopez & Elzière, 2018). In this context the vestibule-ocular brainstem reflex, which supports a stable visual perception (Bonsu et al., 2021), plays an important role. After 20 minutes of VR application, with it's conflicting sensory stimuli, users require 30 minutes break to regain normal function of the vestibule-ocular brainstem reflex (Frank et al., 2022). During this time there is an increased risk of accidents to users (Frank et al., 2022). Processing virtuality is based on the sensory perception of physical reality, which itself is influenced by body perception, the reciprocity of body and mind, and SI (Luhmann, 2015; Spiegel, 2020).

Children under the age of ten have not yet fully developed sensory integrity and must continue to combine multi-sensory experiences with their motor skills, to establish a meaningful, solid connection between mind and body, known as self-awareness. During this phase of child-developmental, digital media might introduce the risk of "fragility", that is a sensitivity regarding the interpretation of physical reality (Schenk-Danzinger & Rieder, 2016). For these reasons, immersive media should only be applied by competent teachers (Hübner et al., 2020). Considering SI is especially important in children between ages six and twelve years, as their psychological development centers around building of self-confidence, and social- and cultural skills advancement (Hetzer & Arbinger, 1995); these act together in shaping "identity". During these sensitive phases of childhood development, the central nervous system, including the brain, is particularly susceptible to external influence (Erikson, 1981; Schenk-Danzinger & Rieder, d2016), including stimuli received from the physical reality, or else VR-generated stimuli. The identity-shaping process requires children to feel in control of their own body and of their sensory-control circuits, which represent the foundation of resonance experiences and, ultimately, development of self-efficacy (Zimmer, 2010). Thus, special consideration should be given when VR-apps are to be used by/with children between ages six and twelve years, to not negatively affect or disrupt this process.

Opportunities and Potential Risks of VR-Use in Schoolchildren

Emotional reactions to VR-experiences are measurable, and similar to experiences in physical reality (Bezmalinovic, 2022). This enriches "storytelling", that is a method of systematically employing dramatical elements to increase memory and information-retention in the brain (Fuchs, 2015), as it emotionally engages users. For example, the VR-application "*Empathy immersed*" (by Meta, 2025) promotes a better understanding of disabled people's daily lives. Here especially, VR-app content must be ethically embedded, and clear user-guidelines provided, to ensure meaningful and safe VR-use in an educational context (Ardai et al., 2022; Bailenson, 2018; Bailey et al., 2019; Bailey & Bailenson, 2017; Yahaya et al., 2022). The application of VR in the field of neurodiversity brings interesting and promising aspects, at times when more frequent occurrence of attention problems present increasing pressure and suffering in classrooms (Gnerlich, 2023). Already VR-training has proven helpful for children with attention-deficit-hyperactivity-disorder (ADHD) (Shum & Pang, 2009), even though ADHD often co-occurs with balance problems, which may in turn contra-indicate therapeutic VR-use.

VR increases the variety of available learning environments (Mulders et al., 2023). VR-training supported motor-learning in physically impaired people (Pavlidou & Walther, 2021), improved SI and psychomotor functions (Burin et al., 2020), and may even improve gross- and fine motor coordination (Huang et al., 2015; Hung-Ying, 2020; Kahlert et al., 2015; J. Lee & Lee, 2021). However, research into long-term effects of therapeutic VR-use is needed, as negative effects cannot be ruled out (Queiroz et al., 2022; Safadel & White, 2020; Schweiger et al., 2022; Yu, 2021). Individual immersion experiences are affected by a VR-user's previous experiences in/with the physical reality, through embodied predictive perception (Litvinova et al., 2022; Schaumburg & Prasse, 2019; Seth, 2015). Children's resonance experiences are typically fuelled by their physical environment (the *real world*), however digital environments can provide additional opportunities, especially for disabled learners in inclusive education, and support participation through special operating devices (Southgate et al., 2019; Southgate & Smith, 2016). Overall, real-world experiences remain the foundation of so-called responsive experiences (where the affected response is as much part of the experience as the received stimuli); as such, "learning by doing is better than a virtual simulation, even at school" (Hübner et al., 2020, p. 70).

Children's appropriate development requires sensory experiences as the foundation for a healthy relationship with the world (Piaget et al., 1993), and it is the real-world that provides the most stimulating multi-sensory experiences. The digital world merely provides an "as-if resonance space" (Hübner et al., 2020, p. 173), where only certain senses are engaged. While a VR-user's attention focus is drawn into VR (through engagement of visual and auditory senses), the rest of the body remains connected to the embodied physical reality, through engagement of the remaining senses (e.g., tactile, vestibular, ...). This leads to a split in people's realms of experience, as multi-sensory stimuli from different realms are not aligned (or even contradictory). Such an incongruence of sensory impressions may lead to a disruption of self-perception, the creation of false memories, depersonalization, and even to dissociation from one's own body, especially in children under the age of ten years (Piaget et al., 1993; Segovia & Bailenson, 2009). Furthermore, children VR-users may not be able to accurately distinguish between real and virtual social beings (Druga et al., 2017; Kahn et al., 2012; Liao et al., 2019). Thus, school-age children between ages six to around 13 years may experience confusion, and consequently experience a disruption of basic developmental skills (Bailey & Bailenson, 2017; Segovia & Bailenson, 2009). Because hardly anything is known about VR-use and aspects of body-sensory development in schoolchildren (Erl, 2023; Steyer, 2023), the natural development of children exploring their real-world environments, and anchoring their own position therein, needs to be safe-guarded (Schenk-Danzinger & Rieder, 2016). The brain has a weakness in distinguishing between physical and virtual reality, and the concept of "reality" is itself dependent on development (Spiegel, 2020; Steyer, 2022). Sensory processing and immersion effects are connected, and come with both opportunities and challenges, as perception can be largely manipulated (Reader et al., 2021). Orientation and identity are based on one's own body perception, as without it one's sense of self is endangered to get lost (Halioua & Claussen, 2022; Widmer Howald et al., 2018; Xu & Zhang, 2022). The immersion effect, associated with reality-loss and disembodiment, is a powerful event that can be measured in the cortex; it may thus represent a challenge for the developing brain (Aspell et al., 2009; Breves & Stein, 2022; Burin & Kawashima, 2021; Furmanek et al., 2021; Jäncke, 2009; Nam et al., 2022; Thirioux et al., 2016; Walk & Evers, 2013). Furthermore, during child-development, moments of fragility occur, that is, critical periods of heightened sensitivity occur, for the learning of certain topics (Vollmer, 2012); thus, aspects of individuality in predictive coding of perception (Valori et al., 2020) must be considered when using VR with children.

However, there are numerous *opportunities for VR application in the education sector:* VR-experiences can support problem-solving skills (Araiza-Alba et al., 2021). It can improve connectivity, build empathy and provide experiences (Hayes, 2022). Ardai et al. (Ardai et al., 2022) list many opportunities for VR-use in special education, such as provision of virtual learning environments that are not otherwise accessible, interactive learning- and skill development, monitoring and evaluation of learning processes, skills-training for independent living, support of behavioral interventions and physical therapy, development of cognitive performance and attention, improving social skills, increasing motivation, and enhance accessibility, specification and individualization of learning environments. Lee & Jin highlighted the improvement of locomotor skills with VR-training (H. K. Lee & Jin, 2023). Raja and Priya (2021) reported students preferred VR for authentic learning, such as in virtual classrooms, over blended learning. On one hand, collaborative- and individualized learning can be supported by VR (Scheffel & Wirth, 2022), but on the other hand it relies on the acceptance by the school system and teachers. VR can be very useful in the field of neurodiversity and therapy, for example in special training for autistic students (Bhatla et al., 2022), or else those with attention deficit (Gnerlich, 2023; Krösl et al., 2018). Several studies show a positive impact on social skills (Duan et al., 2021; Hummer et al., 2023; Kushnir, 2022) as well as on cognitive development (Makransky & Petersen, 2021; Schäfer et al., 2023; Shim, 2023).

However, Hayes (2022) also mentions *risk potentials of VR*, including escapism, isolation and the loss of connectivity with reality. Another example of potential risks for VR-users is the sensory and cognitive strain resulting from the immersion effect; this creates greater stress for people using immersive media, compared to people merely engaged in video conferencing (Immersive Learning News, 2023). Conflicting sensory information experienced during VR-use affect changes in body perception, thus requiring the user's brain to actively make sense of these conflicting messages (rather than being able to "automatically" interpret congruent sets of stimuli familiar since early childhood); this cognitive-load management might considerably challenge a VR-user's brain. In children especially the still developing, and thus fragile sensory system is often not yet able to correctly distinguish between physical and virtual reality (Piaget et al., 1993), which potentially intensifies risks encountered during and after immersion. On one hand, well-functioning SI is important for children's development, and for a child's ability to cope with perceptual disruptions such as these presented by VR. On the other hand, the over-presentation of conflicting stimuli can in itself disrupt SI in children. Understanding and considering these interrelations will be key to risk-safe VR-use with children (Hayes, 2022) and mandates the development of comprehensive expertise among decision-takers, and the development of user-specific guidelines.

INTERVIEWS

Interview Method and Analyses

To answer research question 3 ("What opportunities & risks does VR-immersion present for schoolchildren?"), twelve individually guided expert-interviews (Helfferich, 2020) were conducted between November 2023 and June 2024. Expert interviewees' selection was based on in-depth research in the field, existing contacts and availability. While the selection of interview partners was not quantitatively representative, it was based on representativeness of content in the qualitative sense (Kuckartz, 2014); interviewees represented a variety of relevant fields (including software-development, psychology, VR-research, supervision, consulting, ADHD-therapy, and pedagogy), and hailed from various countries (including Austria, Belgium, Canada, Czech Republic, Germany, Ireland, Italy, and the United States). Guided expert interview questions were mainly informed inductively, from literature review, and included questions regarding immersion level criteria, potential sensory interventions, and the dos and don'ts of VR-user experiences, but also experts' experiences with critical incidents' occurrence. An open final question invited additional information from the interviewees' field of expertise, on opportunities and challenges of VR-use, or else topical aspects not yet considered. Most expert-interviews (11) were conducted online, via

Teams-Meeting, with one in-person interview. In addition to expert-interviews, several anecdotal interviews with children VR-users, aged 5-13 years, were conducted at the "Haus der Wildnis" in Austria (Haus der Wildnis, 2025), where VR-experiences are part of a permanent, ancient-forest exhibit. These interviews, conducted in the presence of children's parents/guardians, followed the Critical Incident Technique (Blokdyk, 2021), and served to anecdotally collect positive as well as negative (*critical incidents*) experiences of children VR-users *in situ*. Interview transcripts, utilizing transcription software integrated in Teams, were edited manually, following individually defined transcription rules based on Mayring (Mayring & Gläser-Zikuda, 2005). Both, guided expert-interviews and anecdotal interviews with children VR-users were analyzed via a mixed-method approach, using Mayring's qualitative content analysis (Mayring & Gläser-Zikuda, 2005), in *MaxQDR* software (MAXQDA, 2025). Interview texts were systematically broken down into small parts and assigned, via coding rules and anchor examples, to the categories formed from the theory or the category system developed on the material. Interview-evaluations were carried out deductively (Kuckartz, 2014), stepwise, resulting in the identification of distinct subtopics intended to clearly summarize opportunities and challenges regarding the connections between SI and VR-use.

Results

Combined findings from literature research and guided expert-interviews served to address opportunities and challenges of VR-use with schoolchildren. These results supported the development of VR-app descriptors that specifically relate to VR-users' sensory perception and SI, and that might consequently support age-appropriate selection of VR-apps for schoolchildren. Results also led to body-senses related use-recommendations developed to support SI before, during, and after VR-use with children.

Sensory functions are generally challenged during VR-immersion and associated disembodiment, because conflicting external- and internal sensory stimuli interfere with meaningfully aligning the "self" (and thus, identity) with its perceived environment. Because similar challenges characterize clinical SI-dysfunctioning, which has long been mitigated by sensory-intervention therapy, the same sensory-interventions strategies may be used to support SI in bridging this discrepancy between perceived external and internal environments during VR-use, and especially during transition from virtual- to actual physical reality. For example, targeted stimulation of proprioception can enhance body-control and torsal muscle-tension and thus improve body-posture control and movement-autonomy. In turn, a well-developed sense of one's own body within one's environment, and effective motoric self-regulation, correlate with perceived self-efficacy, autonomy and self-confidence, and thus affect perceived self-identity. Especially in children, where a sense of reality is still developing, incongruent sensory impressions may cause irritation, create "false (sensory) memories", and even lead to dissociation and physical discomfort (such as cybersickness). Here, the extent of these ramifications depends less on children's actual age, but more on their development-age and relevant sense of reality, with a better developed sense of reality supporting VR-immersion compatibility. Body-sense interventions may focus sensory impressions and consequently support the immersion-experience and disembodiment. Children's VR-experiences should thus be guided by teachers/facilitators cognizant of, and well-trained in, sensory intervention strategies. While many experts intuitively apply some of these mitigating measures after VR-use with children (e.g., physical movement after immersion), a general awareness is lacking the interrelation between SI and the significance of the body's base senses, and consequently, mitigating measures not systematically, or routinely, applied. However, considerable interest in these interrelations is evident among educators, VR-developers, and other stakeholders in applying VR with children, especially since, currently, no VR-use guidelines exist that consider the interrelation between body-sense aspects and VR-use with children.

As long as these interrelations are considered, the VR-technology offers numerous opportunities for VR-use with schoolchildren in various educational settings, and particularly in special education and extraordinary educational circumstances. Specifically, positive potentials/opportunities of VR-use with schoolchildren include: improvement of memory, decreased distraction, individualization through avatar-design, labor simulations, improved intrinsic learning motivation, musical creation (DJ-ing), individualization and inclusion, collaborative learning, practicing communication skills in a safe and protected virtual environment, functional training (e.g. spatial perception), self-regulation (e.g. breathing), conducting social experiences (e.g. with different avatars) without being stigmatized, providing experiences for students with physical disabilities, adaption of body-perception resulting from eating disorders, and many more.

However beneficial its positive potential, VR-use with children must always follow ethical considerations, as well as individual user-requirements, and risks must be considered. Potential contraindicators (e.g., migraines, epilepsy, or immaturity of vestibular system) also must be ruled out in advance. Identified risks include: an inadequately developed sense of reality may lead to challenges with immersion-level, measurable changes in the prefrontal cortex during VR-use, and/or post virtual sadness (e.g. as a consequence of escapism), but also to irritations of spatial relationships in virtual spaces; cognitive or emotional overload and/or cybersickness *per se* may occur, inadequacy of VR-app content may result in additional risks, diminished eye-health, and potential data security- and privacy violations. Overall, the responsible, target-oriented use of VR-technology with school children offers more opportunities than risks.

SUMMARY AND PRACTICAL IMPLICATIONS

In this paper we discussed, how VR-immersion affects schoolchildren, how SI-functionality relates to VR-immersion, and what opportunities and risks are thus presented. In general, VR-technology affords great opportunities to promote learning and support inclusion. However, caution is warranted when planning VR-use with school-age children, as VR-immersion experiences may affect children's health and their development, and especially the formation of a sense for actual, physical reality, as well as identity. VR-immersion should be informed by expert-knowledge, address body-sensory aspects and eye-health, and be guided by competently trained adults/ facilitators/ teachers. User-age recommendations refer to children's development-age and are based on developmental maturity. Here, potential sensory- and/or emotional exertion (that is, critical incidence occurrence, such as cybersickness) must remain focus. Facilitators and teachers must be aware of contra-indicators to VR-use, should generally optimize external conditions in support of VR-use, and should individually select appropriate VR-apps. To that end, a summary of a VR-app's immersion criteria and assessment parameters (i.e., immersion level, content, ...) should routinely accompany all VR-apps (see Table 1). The description of external factors, which also determine the immersion effect, could usefully supplement application notes to better assess and classify VR-apps. Training of competent teachers/ facilitators in this context is indispensable.

Regarding research-question 3 ("What opportunities and risks does VR-immersion present to schoolchildren?"), many opportunities exist for VR-use in education, but risks to school-age users need be considered, in light of potential cognitive overload, developmental disruption but also potential physical injury. Risks can be minimized at several levels of VR-use with schoolchildren, first when selecting appropriate VR-programs, second, at the hardware level, and third, during VR-use, when implementing mitigating measures. In general, VR-use is only recommended for children 7-8 years or older, or after their ability to recognize actual physical reality has sufficiently developed. With increasing age, children are increasingly able to distinguish between actual and virtual reality, and to successfully navigate VR, which may be supported by adjusting VR-app immersion-level and/or interactivity. To determine optimal adjustment-level for individual users, a questionnaire might serve to identify potential VR-use contra-indications and previous VR-experience, and SI-maturity might be formally assessed (e.g., nystagmus-test for vestibular maturity). Safe VR-use with schoolchildren requires a variety of user's body-senses to remain engaged during VR-experience, to support compatibility and facilitate user's transition between virtual and physical realities. Otherwise, the VR-immersion experience might quickly exceed children's capability of effectively managing cognitive-load.

Recommendations Regarding VR-App Selection, and Physical Aspects of VR-Use

Because sensory perception as well as physical characteristics vary considerably among individuals, standardized settings of both software and hardware are likely suboptimal for many VR-users. Options for individual adjustment of involved software (VR-programs or -apps), but also hardware (e.g., headsets, controllers) should thus be available, and these should be known to teachers and facilitators implementing the VR-experience. To that end, step-by-step guidelines for hardware- and software adjustments are needed. Additionally, the selection of development-age-appropriate VR-apps for use with schoolchildren would greatly be aided by a description of VR-app immersion-level, as younger and/or less experienced VR-users require VR-apps of lower immersion intensity. As it stands, VR-app "notes" provided by app producers do not routinely include such descriptions, however children's immature SI warrants such considerations. Immersion-level descriptors should address user perspective (3rd-person vs. 1st-person perspective), visual quality (low- vs. high resolution image), audio quality (low vs. high-fidelity sound-quality), interactivity (experience only/passive, vs. active single-, vs. multi-player), involvement (experience only/passive, vs. active hand motion, vs. full-body tracking), freedom of movement within the app (3 DOF: limited mobility in the virtual space/viewer-perspective, vs. 6 DOF: full mobility in the virtual space/full immersion), recommended body-position of VR-user during immersion (seated, vs. standing, vs. moving), and lastly avatar options (only available in 3rd-person mode; low- vs. high realism in player representation). Table 1 depicts immersion-level descriptors, together with immersion-intensity adjustment-levels. Adjustment levels are listed in order of increasing immersion-intensity, where lower-order immersion levels are listed first.

TABLE 1
PROPOSED CRITERIA TO DESCRIBE VR-APP IMMERSION LEVEL, AS DERIVED FROM EXPERT-INTERVIEWS, TO INFORM CONSUMERS/USERS AND THUS SUPPORT DEVELOPMENT-AGE-APPROPRIATE VR-APP SELECTION, AUTHOR

Relevant criteria	Description (from lower to higher immersion level)
User perspective	3rd person viewpoint 1st person viewpoint
Visual quality	Low resolution High resolution
Audio quality	Low sound quality High sound quality
Interactivity	Experience only /passive viewing Single player Multi-player
Involvement	Experience only /passive viewing Hand motion Full body tracking
Degrees of freedom (DOF) / user in-app mobility "Freedom of movement within the app"	3 DOF /viewer perspective: limited mobility 6 DOF / full mobility, full immersion
VR-user body-position during immersion	Seated Standing Moving
Avatar options (in 3rd person view)	Low realism in player-representation High realism in player-representation

Source: Author

These immersion-level descriptions, together with content information, should routinely be included in VR-app "notes" provided by developers/producers/distributors, to inform consumers/users, and thus support age-appropriate use of VR-apps. In addition to VR-app descriptors, VR-hardware aspects should be considered. VR-hardware is designed to fit (male) adult user's bodies, and thus hardware was mostly found suboptimal for use with children. Headsets often did not fit well on smaller heads, and headsets' inter-ocular distance often exceeded that of children VR-users, as their eyes were set closer together than adults' eyes; this added another layer of "unfamiliar" visual stimuli, sometimes even interfering with the immersion experience. Headsets' weight posed a particular challenge for children VR-users, as it strained children's neck- and shoulder musculature and upper vertebral column, thus eliciting unfamiliar muscle-tonus sensory stimuli. Also, VR-controllers (where VR-immersion was interactive) often were too large for children's smaller hands, which disturbed VR-user's attention-focus during VR-experience. In summary, ill-fitting hardware introduced yet additional strain on children's cognitive load during immersion, the sum of which may exceed children's cognitive-load management abilities; critical incidence occurrence may thus become more likely. VR-hardware settings should be adjusted, as far as this is possible (Meta, 2025b), including adjustments to headset's volume and brightness, to accommodate VR-user's sensitivity. Additional measures might be taken to optimize physical aspects of VR-use with children, e.g., VR-users may support VR-headset with their hands, with elbows resting on a table (to decrease headset weight), or supportive furniture (such as chairs with headrests) may be employed during VR-immersion.

Body-Senses Related Specific Recommendations for VR-Use With Schoolchildren

Derived from literature review findings and expert interviews, we identified and list here specific recommendations addressing SI fragility in children VR-users. These were grouped based on when, relative to the VR-experience, they should be applied, that is, (1) during VR-use planning, (2) during *in-situ* preparation (see Table 2), (3) during the actual VR-experience, or else (4) following the actual VR-experience (see Table 3). Thus, during the planning phase, a teacher/facilitator should first rule out the presence of contra-indicative conditions (e.g., epilepsy, migraines, psychosis, etc.) in intended VR-users and verify user age (7 years or older). Use-duration of any one session, break duration between sessions, and total daily VR-use time should be decided on at this time, according to intended VR-user's development-age and previous experience with VR (10- max. 30 mins per session, with 30 mins break in between sessions, and no ore than 90 mins daily VR-use). Lastly, the use of a buddy-system should also be organized in this planning phase, as buddies need be identified and their respective responsibilities stipulated; in general, VR-immersed users are accompanied by non-immersed buddies that keep VR-users in touch with physical reality via voice or touch. Hardware for screen sharing between VR-users and their buddies need also be organized during the planning phase. Preparation *in situ* should include preparing the physical space and other physical aspects (clear space of potential obstacles to match user's anticipated action-radius and adjust furniture and hardware to fit user's individual requirements), and address time-management (set timer to desired use-time; adjust timer volume to user-sensitivity). VR-content should at this time be matched with user development-age and experience, immersion-level settings adjusted, and the VR-app tried out by teachers/facilitators *in situ*, before use with children. Give personal instructions to VR-users at this time; tell them what to expect and encourage them to communicate during VR-experience any unusual sensations they might have (this sensitizes children to consider and express how they feel). Lastly, it is important to prepare VR-user's body-senses for immersion, by stimulating user's bodily self-awareness; VR-users should pat, stroke, and knead their own extremities, lower belly and lower back, to better "feel" themselves before embarking on their virtual experience.

During VR-use, measures to support user's body position should remain active, that is inexperienced users should start in a seated position, and torso and head should be supported though adequate furniture (with back- and headrest) or else pillows. Teachers/facilitators should mitigate VR-user's transition between physical and virtual realities (in both directions), and accompany/guide the VR-experience, by providing both, verbal and tactile stimuli; for example, facilitator might inquire about VR-user's well-being, establish body contact (e.g., lay hand on shoulder of VR-user), and announce approaching end of VR-experience. Session duration also needs be observed; enforce session end firmly, but gently.

TABLE 2
PROPOSED VR-USE RECOMMENDATIONS FOR RISK-MINIMIZED VR-IMMERSION WITH SCHOOLCHILDREN, BASED ON EXTENSIVE LITERATURE REVIEW AND EXPERT-INTERVIEWS. RECOMMENDATIONS ARE GROUPED BASED ON TIMING RELATIVE TO ACTUAL VR-EXPERIENCE: PLANNING, PREPARATION

	Recommendation for VR-Use with schoolchildren	**Explanations**
PLANNING PHASE	Rule out presence of conditions that contra-indicate VR-use	VR-user should not suffer from epilepsy, migraine, severe psychosis, or similar conditions.
	Check and heed user age	Minimum: 7 years, when sense of reality has developed
	Limit VR-use duration per session, prepare time-measuring device	Start with 10 min for inexperienced users; may increase to 30 min, depending on user.
	Schedule breaks between repeated sessions; prepare time-measuring device	Break duration should be 30 min or more.
	Limit total daily VR-use duration	No more than 3 repetitions daily (thus daily use should be limited to 90 min)
	Employ buddy-system	A "buddy" is a person that stays physically close to the VR-user during the experience, to observe and assist the user's well-being during VR-use (ask, "are you ok?", …).
	Employ "screen sharing"	Project the VR-image onto an external screen, for another person (buddy) to observe the user's experience and thus better assist, if necessary.
PREPARATION *in situ*	Prepare physical space/-aspects	Clear all potential obstacles from the user's environment, to match the VR headset's declared action radius. Adjust furniture/hardware to fit user.
	Manage time	Set a timer to desired immersion time (10 min) - buddy might use an hourglass.
	Manage content-related issues	Carefully match application content with user development-age and experience. Adjust immersion-level settings to match user development-age and experience. Try out application *in situ* before using with children.
	Give personal instruction	Verbally instruct the user what to expect during the VR-experience. Encourage user to speak up and describe any unusual sensations that might arise during VR-use.
	Prepare user's body-senses	Stimulate bodily self-awareness: user pats, strokes, and kneads own extremities, lower belly and lower back.

Source: Author

TABLE 3
PROPOSED VR-USE RECOMMENCATIONS FOR RISK-MINIMIZED VR-IMMERSION WITH SCHOOLCHILDREN, BASED ON EXTENSIVE LITERATURE REVIEW AND EXPERT-INTERVIEWS. RECOMMENDTIONS ARE GROUPED BASED ON TIMING RELATIVE TO ACTUAL VR-EXPERIENCE: DURING AND AFTER

	Recommendation for VR-Use with schoolchildren	Explanations
DURING VR-USE	Apply accompanying measure: body position	Inexperienced users: start in a seated position, stabilize torso and possibly head (with back- and headrest, or else with pillows).
	Facilitate transition between physical and virtual realities: verbal	Verbally accompany/guide the experience, inquiring about well-being, announce approaching end of experience.
	Facilitate transition between physical and virtual realities: tactile	Establish body contact, e.g., lay hand on shoulder of VR-user.
	Observe session duration	End session when time is up.
AFTER VR-USE	Apply supportive measures regarding body position	VR-user should remain seated for a little while after VR-experience.
	Offer supportive measures for body/brain function	VR-user should take a sip of water.
	Support the activation of VR-user's body-senses	VR-user pats, strokes, and kneads own body, working from the feet upwards, thus providing proprioceptive and tactile input.
	Support spatial perception of physical reality (distances, sizes) after VR-use	User winds their way among furniture in a room, and experience spatial conditions through touching walls, floor, furniture. User walks to a window and looks into various distances.
	Exercise eyes to activate distance-vision	User gazes into distant physical environment - play "I spy with my good eye…" with distant objects.
	Support arrival in physical reality through buddy-system	User speaks with a buddy about the VR-experience.

Source: Author

Immediately after VR-use, teachers/facilitators should apply supportive measures addressing VR-user's body-position and body-/brain function; children should remain seated for some time after immersion end (to help the visuo-vestibular system to adjust) and drink some water. Now again, VR-user's body-senses need to be activated, by providing proprioceptive- and tactile sensory input; VR-users should pat, stroke, and knead their own extremities, lower belly and lower back (working from the feet upwards) to redirect attention-focus back to their own bodies after VR-experience. Spatial perception (that is a sense for the distance and size of objects in physical reality) also need to be activated at this time; teachers/facilitators should guide children in experiencing the "spatial conditions" of their physical surroundings (e.g., children touch walls, windows, and floors, and wind their way among furniture in a room), and in exercising their distance vision (e.g., children gaze out the window, into the distance, and identify/name distant objects). Lastly, arrival in the physical reality after VR-experience can be supported though buddy-systems; children relate their VR-experience to a buddy, describing what they saw and how they felt during VR-use. Observing these recommendations should minimize the immediate risk of critical incidence occurrence during/immediately following VR-use and minimize risk of development disruptions that may potentially result from inappropriate VR-use with schoolchildren.

OUTLOOK

The interconnectedness of body-perception, equilibrium, and SI, especially as it relates to VR-technology, should be investigated further, as VR-immersion affects and even irritates the vestibular system; SI is thus closely linked with development-appropriate use of immersive media. Furthermore, because SI directly affects torso muscle-tone, and consequently increases body stability, which in turn improves VR-compatibility and reduces critical incidence occurrence, SI effects on body stability warrant further investigation. Owing to these sensoric aspects of VR-use, further research is needed into the effectiveness of applying mitigating measures in concert with VR-immersion. Here specifically, studies are needed into how children's prior, real-world sensory experiences relate to VR-compatibility, and how preparatory measures (with a focus on visual- and body-perception), presented to children VR-users in physical reality, ultimately facilitate transition between physical reality and VR/virtuality. On one hand, general research into the long-term effects of VR-use with children is required, with a focus on SI, while on the other hand specific research should provide evidence for effectiveness of targeted mitigating measures, and potentially identify additional measure to accompany VR-use, and especially with schoolchildren. The connection between the functional principles of VR-immersion and SI-related therapeutic principles also warrants further research, as it would benefit both, VR-use risk minimization, as well as supporting SI-therapy. Existing guidelines and recommendations for VR-use with schoolchildren, and for the development of child-appropriate VR-apps, should be expanded on, with a special focus on SI and the use-recommendations presented in this paper. In the future, ramifications of VR-immersion should more routinely be taken into account, especially since the creation of VR and extended reality will increasingly rely on artificial intelligence, thus potentially further impede children's ability to accurately distinguish between actual and virtual reality.

LIMITATIONS

Technology of immersive media and artificial intelligence advances quickly, and findings presented here may soon prove not comprehensive. Availability and affordability of newly developed VR-hardware may quickly shift user priorities and thus warrant adjustments in use-recommendations; for example, the arrival of Quest 3s models on the VR-scene increased focus on extended reality, and on the effects of rapidly occurring transition-events. Increased use of artificial intelligence in creating VR, developing extended-reality software, and guiding virtual experiences requires constant awareness-update; however, this is not addressed here, as this study focussed on immersive VR. Interviewee selection was limited to twelve available experts; however, for this qualitative study they represented the diversity of relevant fields of expertise. While it would have been interesting and appropriate to formally include children VR-users' voices in this study, working with children requires specific research arrangements that exceeded the scope of our study. Furthermore, children are often not yet able to recognize and/or accurately describe how they feel during VR-immersion; thus, expert-observations of children VR-users during immersion provided the only reliable information regarding body-sense related events and critical incidence occurrence.

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