Overcoming Pain with Virtual Reality: Exploring the Potential of VR as a Tool for Pediatric Pain Management

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Highlights
Virtual Reality interventions are a relatively new approach in pain management for children and adolescents, however, research in this field is growing.
Two not mutually exclusive theories emerged on how VR can decrease acute and chronic pain:
(1) via distraction – VR has been repeatedly tested as a distraction tool in experiments as well as in clinical contexts, especially for acute pain. There are strong indications in literature pointing towards a pain-relieving effect of VR, however the evidence is weak and relevant studies are not systematically comparable due to unstandardized methods and different age groups, as well as partially insufficient sample sizes and open questions regarding the used paradigms.
(2) via embodiment – experimental studies indicate that ownership and visual modification of a virtual body part may decrease pain perception in this body part, however this approach has not been sufficiently tested in a clinical context yet; in particular, more evidence for children and adolescents and with regards to acute versus chronic pain is needed.
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Pediatric medical interventions are unavoidably associated with stress and anxiety for children, and are often connected to some level of pain (Franck et al., 2000; McGrath et al., 2008; Racine et al., 2016). Pain during medical procedures is related to higher levels of stress and anxiety, which in turn can increase pain perception in future procedures as well as induce health care avoidance behavior (Blount et al., 2006; Racine et al., 2016; Sajeev et al., 2021; Verschueren et al., 2019). Furthermore, higher pain levels are linked to a decrease in children's and adolescents' adherence as well as longer recovery periods (Sajeev et al., 2021; Verschueren et al., 2019). This all renders pain management a crucial element in successful pediatric patient care. Especially with children, studies show that pain reducing interventions and medication often do not suffice in the management of health care related pain (Lambert et al., 2020; Schug et al., 2020). This is why non-pharmacological techniques are being developed in order to improve pharmacological pain administration (Sajeev et al., 2021).

One relatively new approach in the optimization of pain management for children and adolescents is a Virtual Reality (VR) intervention. VR in general is a relatively old technology that has been developed decades ago (Greengard, 2019; Szàkely & Satava, 1999). The implications of a virtual environment that can be altered in any way or form imaginable are clearly endless, and as such it is of no surprise that VR has gained importance as an application in medicine as well (Greengard, 2019). VR is currently tested and used as an educational and training tool, in operational planning, diagnostics, rehabilitation and therapy (Greengard, 2019; Javaid & Haleem, 2020; Szàkely & Satava, 1999). One of the largest fields of research in this regard is the usage of VR as a tool in pain reduction, as this technology is becoming increasingly accessible and sophisticated. However, the exact mechanisms by which VR reduces pain levels are still subject of ongoing research. In general, two types of mechanisms are highlighted: distraction and embodiment.

1 VR as a distraction

The main paradigm suggests that VR decreases pain reception by distraction (Eijlers et al., 2019; Lambert et al., 2020). Distraction is a common instrument in clinical contexts to reduce pain and stress (Koller & Goldman, 2012). The distracting stimulus is competing for cognitive resources and therefore, less capacity is left for an active perception of the painful input (Gaultney et al., 2021; Koller & Goldman, 2012; Moont et al., 2010). This effect has been shown in several imagery studies where pain associated brain activity was suppressed, whereas areas that are connected to attention and conscious control were more active instead (Bantick et al., 2002; Lambert et al., 2020; Morris et al., 2009; Petrovic et al., 2000; Valet et al., 2004).

Several studies have researched different distraction strategies that can be categorized as active and passive distraction (Koller & Goldman, 2012). Passive distractions like music or movies, where no action by the patient is necessary, have significantly reduced pain in several pediatric studies (Birnie et al., 2018; Eijlers et al., 2019; Koller & Goldman, 2012). Methods of active distraction, in turn, integrate the patients in the activity, for example video games or breathing techniques; these forms of distraction have also been proven useful in pain reduction (Birnie et al., 2018; Dahlquist et al., 2002; Koller & Goldman, 2012). In their meta-analysis, Koller and Goldman (2012) concluded, that both forms generally work, however there is some ambiguity as to which one works better and for which age group. Generally, several experimental studies have shown advantages of strong distractions that require greater cognitive resources for pain reduction in children in comparison to easy tasks (Dahlquist et al., 2020; Gaultney et al., 2021), however there is a lack of validation for the clinical context. VR is a promising tool in this regard because it combines auditory, visual, and often also tactile components to an intensive and immersive experience that makes it especially effective in distracting patients (Dahlquist et al., 2009; Koller & Goldman, 2012).

Nevertheless, it is not completely clear that the pain reducing ability of VR is completely due to the distraction it enables. Especially in research about the effects of VR on chronic pain relief, another mechanism is hypothesized (Keefe et al., 2012; Loreto-Quijada et al., 2014).

2 Pain reduction through embodiment

The concept of embodiment assumes that visual manipulations of the patient's body modulate pain perceptions (Matamala-Gomez et al., 2019a; Schug et al., 2020). Being embodied in a virtual body offers the opportunity of making visual changes to the affected body part and hence, induce analgesia via the so-called embodiment illusion. The actual control of a virtual self in a VR environment could additionally cause a sense of control over the real body and thereby increase self-efficacy and reduce the feeling of helplessness (Loreto-Quijada et al., 2014; Matamala-Gomez, et al., 2019a). Embodiment is not a new concept and has been tested repeatedly with rubber or mannequin hands and arms for adults (Botvinick & Cohen, 1998; Matamala-Gomez, et al., 2019a; Petkova & Ehrsson, 2008). In 2008, this effect could be replicated by Slater and colleagues for VR and has been tested for chronic pain since (Matamala-Gomez, et al., 2019a; Slater et al., 2008). Based on the meta-analysis of Matamala-Gomez et al. (2019a), however, it becomes obvious that this approach to pain is still in an early phase of research. The majority of studies work only with healthy patients and experimental thermal pain (Matamala-Gomez, et al., 2019a), nevertheless, they are successfully debunking the mechanisms of this paradigm: The important factor in pain threshold decrease is the feeling of ownership of the virtual body part, which can be induced by synchronous movements of virtual to real body part and is affected by size, transparency and positioning of the virtual representation (Martini et al., 2014, 2015; Pozeg et al., 2017; Romano et al., 2016). Matamala-Gomez et. al (2019b) could replicate these findings in their study with chronic pain patients. Another study including patients with chronical pain found that ownership induced by synchronization with their own heartbeat could reduce pain and improve function of the affected limb depicted virtually (Solcà et al., 2018).

Even though there are indications that the ownership of a virtual body part reduces pain and increases the pain threshold in experimental studies, the question of the replicability in clinical contexts is yet to be answered. Pozeg and colleagues (2017) for example found that patients with a spinal cord injury could not achieve the same level of ownership in the VR as healthy patients, whereas in another study, the patients with complex regional pain syndrome achieved the same ownership of the virtual limb as the healthy control group (Matamala-Gomez, et al., 2019b). Only one study was found using VR-embodiment as a pain reducing therapy in children and adolescents with chronic headaches, however this was a pilot study with only ten patients and without an immersive HMD (Shiri et al., 2013). More evidence is needed from experimental studies with chronic and acute pain patients. Additionally, investigations of this model in a clinical context are crucial in developing possible rehabilitation concepts for chronic pain and finding effective applications for acute painful procedures, especially in children.

3 Pain reduction in clinical contexts

Regardless of the actual way VR reduces pain perceptions, the question remains if it really works in a medical context. Experimental laboratory studies have already shown a significant pain relieving effect of VR in children and adults (Dahlquist et al., 2009; Malloy & Milling, 2010; Patterson et al., 2006). Corresponding studies using VR in a clinical context show that immersive VR delivered via head-mounted-displays (HMDs) with a 360° field of view may significantly reduce pain compared to simple analgesia during painful physiotherapy for pediatric burn victims (Das et al., 2005; Hoffman et al., 2019; Schmitt et al., 2011). Similarly, a virtual environment was able to reduce fear and pain during dental procedures, which are particularly feared by children (Shetty et al., 2019; Zaidman et al., 2022). During routine medical procedures like venipunctures and

Table 1. Characteristics of studies in children and adolescents using VR distraction techniques in a clinical context.

Study	Mechnism	Sample	VR Technology	Control group	Study Design	Clinical Intervention	Outcomes	Effect Size
Althumairi et al., 2021	Passive distraction	4–6 years (N=104, n_{VR}=53)	HMD with 3D adventure movie	No distraction reported	Between-group quasi-experimental design	Vaccination	FPS; sign. reduced pain in VR (*p*<.001)	Not reported
Clerc et al., 2021	Passive distraction	6–16 years (N=64, n_{VR} =35)	HMD with 'Rollercoaster'	DVD movie, tablet or smartphone, music, jokes, discussion, handholding	RCT	Minor plastic surgery procedures (Excisions, Biopsies, Scar revisions, partial wound closure, steroid injections, …)	FPS; no sign. reduced pain in VR (*p*=.60)	Not reported
Das et al., 2005	Active distraction	5–18 years (N=9)	HMD with 'Quake' Game	No distraction reported	Within-subject-design	Dressing change for burn victims	FPS; sign. reduced pain in VR reported (*p*<.001)	Not reported
Erdogan & Aytekin Ozdemir, 2021	Passive distraction	7–12 years (N=160, n_{VR} =37)	HMD with 3D dinosaur animation	No distraction reported	RCT	Venipuncture	VAS & FPS; sign. reduced pain in VR (*p*<.001)	VAS: η^2=.157; FPS: η^2=.215
Gold & Mahrer, 2018	Active distraction	10–21 years (N=143, n_{VR} =70)	HMD with 'Bear Blast' Game	Television with a cartoon movie	RCT	Blood draw	VAS; sign. reduced pain in VR (*p*= .001)	Not reported
Gold et al., 2006	Active distraction	7–17 years (N=20, n_{VR} =10)	HMD with 'Street Luge' Game	No distraction reported	RCT	Venipuncture	VAS; sign. increased pain in control group (*p*<.05) and no sign. increased pain in VR group	Non reported
Goldman & Behboudi, 2021	Passive distraction	6–16 years (N=66, n_{VR} =33)	HMD with 'Rollercoaster'	Videos, Television, iPad, child life specialist	RCT	Venipuncture	FPS; no sign. reduced pain in VR (p=.93), however significantly lower median pain score after procedure (*p*=.004)	Not reported
Hoffman et al., 2019	Active distraction	6–17 years (N=48)	HMD with 'SnowWorld' Game	No distraction reported	Within-subject-design	Wound care for burn victims	GRS; sign. reduced pain in VR reported (*p*<.001)	*d*=.82 to 1.03
Kipping et al., 2012	Active distraction	11–17 years (N=41)	HMD with 'Chicken Little' Game (under 14); 'Need for Speed' Game (over 14)	Television, stories, music, caregivers, or no distraction	Within-subject-design	Dressing change for burn victims	VAS; no sign. reduced pain in VR (*p*=.16)	Not reported

Table 1. continued

Study	Mechnism	Sample	VR Technology	Control group	Study Design	Clinical Intervention	Outcomes	Effect Size
Mohanasundari et al., 2021;	Passive distraction	3–12 years (N=105, n_{VR}=35)	HMD with TV cartoon comics	Storytelling, verbal diversion	RCT	Venipuncture, blood draw, intramuscular injections	FPS; sign. reduced pain in VR (*p*<.001)	Not reported
Özalp Gerçeker et al., 2020	Passive distraction	5–12 years (N=136, n_{VR}=90)	HMD with 'Ocean Rift' or 'Rollercoaster'	No distraction	RCT	Blood Draw	FPS; sign. reduced pain in VR (*p*<.001)	Not reported
Piskorz & Czub, 2018)	Active distraction	7–17 years (N=38, n_{VR} =19)	HMD with self-designed game (Multiple Object Tracking)	No distraction	Between-group quasi-experimental design	Venipuncture	VAS; sign. reduced pain in VR (*p*<.02)	*d*=.863
Schmitt et al., 2011	Active distraction	6-19 years (N=54)	HMD with 'SnowWorld' Game	No distraction reported	Within-subject-design	Physical therapy for burn victims	GRS; sign. reduced pain in VR (*p*<.05)	Not reported
Shetty et al., 2019	Passive distraction	5-8 years (N=120, n_{VR}=60)	HMD with TV cartoon show	Conversation, Tell-Show-Do, voice control, …	RCT	Dental treatment (vital pulp therapy)	FPS; sign. reduced pain in VR (*p*<.001)	Not reported
Shiri et al., 2013	Embodiment	10-17 years (N=10)	2D self-representation	No control group	Single arm pilot study	Chronic headache	VAS; sign. reduced pain in VR (*p*<.05)	Not reported
Zaidman et al., 2022	Passive distraction	4-12 years (N=34)	HMD with "age-appropriate content"	No distraction reported	Within-subject-design	Dental treatment (rubber dam placement)	FPS; sign. reduced pain in VR (*p*=.005)	η=.52

FPS = Face Pain Scale, GPS = Grafic Pain Scale, HMD = head mounted display, RCT = randomized controlled trial, VAS = Visual Analog Scale

Note: As this article does not constitute a systematic review of literature, the depiction of studies in this table is not exhaustive; it only details the studies mentioned in the text.

other injections (Erdogan & Aytekin Ozdemir, 2021; Gold et al., 2006; Mohanasundari et al., 2021; Piskorz & Czub, 2018), as well as during blood draws (Gold & Mahrer, 2018; Mohanasundari et al., 2021; Özalp Gerçeker et al., 2020), vaccinations (Althumairi et al., 2021), the effects of VR as a pain reducing agent for children and adolescents have been shown. Additionally, the use for chronic pain management was studied more intensely in recent years (Wong et al., 2022). However, there are also some studies that could not replicate these effects in clinical contexts for children (Clerc et al., 2021; Goldman & Behboudi, 2021; Kipping et al., 2012). For an overview of mentioned studies see Table 1.

Considering the probable publication bias, a closer look into these findings is necessary to assess the true effect of VR in pain management. A meta-analysis by Eijlers et al. (2019) included 14 studies on children and adolescents and found a significant reduction of pain with VR compared to the Standard of Care (SoC) with a medium to high effect size. This analysis included only HMDs, whereas a Cochrane Review (Lambert et al., 2020) allowed any kind of VR technology, including also 2D-screens. This publication included 17 RCTs and discovered a low to very low certainty of evidence for the effectiveness of VR for pain reduction in children and adolescents. These vast differences in two very recent meta-analyses reveal pending open issues in this field of research. All the above reported studies on VR-based pain relief for children and adolescents in a clinical context are summarized in the supplementary material (see supplementary table 1). Please note, that this letter is not a systematic review and therefore the list of studies presented here is not exhaustive.

Most of the studies published on this topic are not standardized with regards to the VR technology they are using. The level of immersion (i.e., HMD vs. 2D-screen) is not consistent across different studies, which supposedly affects the level of distraction a VR system is able to induce (Felnhofer & Kothgassner, 2022; Triberti et al., 2014; Won et al., 2017). Even though some studies control for the level of immersion, there is no definite evidence that suggests an advantage of an immersive VR technology vs. non-immersive VR in the context of pain management (Eijlers et al., 2019; Won et al., 2017).

In addition, the question of whether active engagement vs. passive distraction is more effective has yet to be resolved (Dahlquist et al., 2020; Eijlers et al., 2019; Koller & Goldman, 2012). Furthermore, the level of engagement could depend on the type of game that is played in the virtual environment. Most research groups program their own game or use a preexisting one, except for studies with burn patients which mostly implement the "SnowWorld" non-profit VR game (Eijlers et al., 2019; Hoffman et al., 2019; Lambert et al., 2020; Won et al., 2017). At the same time it is important to notice that a meta-analysis from 2016 could not find significant differences between the pain reduction of various software (Kenney & Milling, 2016). Another problem with comparing previous studies is the definition of Standard of Care (Eijlers et al., 2019). Some hospitals may have a television in the room and watching a movie is part of the routine pain management. Additionally, the pharmacological pain management might differ.

The second main problem that affects the comparability of studies on VR-based pain-management are the different age groups in the samples. There is no standardization of age across research, which can reach from five-year-old children to eighteen-year-olds (Eijlers et al., 2019; Lambert et al., 2020). Furthermore, small sample sizes within each age group hamper reliable between-group comparisons. Some evidence suggests that VR interventions reduce pain more efficiently in younger children, possibly because they engage more in a technology that might feel more exciting to younger age groups (Eijlers et al., 2019). However, Dahlquist et al. (2009) found, that children under the age of ten do not benefit from VR distraction as compared to the older age group possibly due to differences in cognitive development, attention regulation and size of available HMDs. These interactions with age make it difficult to explore true effect sizes and therefore, Lambert et al. (2020) suggest to clearly define age groups in future studies as suggested by the US National Institutes of Health, which would separate children up to twelve years from adolescents ranging from thirteen to seventeen (National Insitutes of Health, 2022).

4 Conclusion

Overall, existing research on the topic has systematical problems regarding study quality. Further high-quality research is needed that includes adequate sample sizes and hence, allows in-depth analysis of involved mechanisms (Lambert et al., 2020). This would facilitate the differentiation of effects on various age groups and provide a clearer picture of the true effect sizes, which are questionable at the moment (Eijlers et al., 2019; Lambert et al., 2020). There is a lack of control for cost-effectiveness and comparison of immersive VR to other, less immersive distraction tools like tablets or handheld gaming consoles, as well as a research gap in the contrast between active and passive distraction (Koller & Goldman, 2012; Lambert et al., 2020). Similarly, it is unclear whether embodiment-based techniques may be superior to distraction methods, and whether specific visual modifications to affected body parts may be contingent on specific types of pain perceptions (Matamala-Gomez et al., 2019a). Accordingly, it has been suggested that tailored embodiment experiences may be particularly effective in addressing patients' unique pain perceptions and provide the most successful analgesia among non-pharmacological approaches.

Generally, this field of research is relatively new and the limited number of trials with limited types of experimental pain induction procedures and pain levels does not yet allow for solid conclusions. This is why, in summary, the question of whether VR is actually effective, particularly in clinical settings, cannot be definitively answered (yet), even though many studies categorically point in the direction of VR as a useful and exciting new tool in pain management.

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