Examining Research with Children and Immersive Virtual Reality

Jakki O. Bailey

Jeremy N. Bailenson

Stanford University

450 Serra Mall, Building 120

Stanford, CA 94403

Corresponding author: Jakki Bailey, jakki7@stanford.edu

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Abstract

What do we know about children and immersive virtual reality? Research shows virtual experiences impacting adults' behaviors, thoughts, and social lives, yet little is known about users under the age of eighteen. This paper provides a state-of the-art review and content analysis of empirical studies on immersive virtual reality (IVR) and children, including a table with an overview of each study. The results from the analysis show a small number of existing studies. Four major research themes arise (pain distraction, education, assessment, media effects), and much of the existing research has focused on IVR use with clinical populations. Sample sizes varied greatly, and studies had small to extremely wide age ranges. In addition, little research examined the developmental media effects of IVR on children, particularly those in early childhood. The implications of these results, issues of cognitive development and IVR, and future research are discussed.

Key terms: virtual reality, children, HMD, immersive, CAVE

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In today's current media landscape, youth are gaining greater access to media-technology and demonstrating that they use media early on. For example, children under the age of eight use screen media for an average of two hours a day, and in 2013, 80% of parents reported that their two to four olds have used a mobile device (i.e. smart phones, tablet; Rideout, 2013). The consumer market is feeding into the growth of child media users: 80% of the top-selling education apps target children, with 72% specifically targeting preschool-aged children (Guernsey, Levinue, Chiong, & Severns, 2012). Beyond mere access, children and adolescents adopt of new media technologies early (Lauricella, Cingel, Blackwell, & Conway, 2014) suggesting that as the affordances and capabilities of media evolve, children will be at the forefront.

Immersive and interactive technologies like immersive virtual reality (IVR) are gaining traction in the public and consumer arena. Immersive virtual reality technology places users directly into a virtual environment that blocks out the outside world, creating intense, vivid, and personal scenarios (Bailey et al., 2015; Bainbridge, 2007; Blascovich, & Bailenson, 2011). For decades IVR was only available to major institutions such as universities, hospitals, and government military agencies. However, IVR is becoming more accessible to the general public. Large media corporations are purchasing IVR companies for billions of dollars (Solomon, 2014) and IVR hardware alone is projected to be a billion-dollar business (Lamkin, 2015).

Although virtual reality research has decades worth of work demonstrating IVR's powerful effects on adult attitudes and behaviors (Blascovich & Bailenson, 2011), little is known about how children, particularly in early childhood (i.e. ages 3-6 years old) respond. Greater access to the technology suggests that young children will experience IVR, raising questions on its relationship to child development. This paper moves towards better understanding the effects of IVR on children by providing an analysis of the empirical research on immersive virtual reality research and children, including a table that outlines each study. The paper defines IVR, and identifies the trends in research. Finally, we discuss the findings from the content analysis and their relationship to child development. The paper concludes describing issues to consider for IVR and early childhood, and future directions.

Defining Immersive Virtual Reality (IVR)

Media comes in all shapes, sizes, and levels of immersion; even within a specific medium like virtual reality there is variation. Immersion is defined by the objective capabilities of the technology (Bowman & McMahan, 2007; Slater, 2009). The level of immersion relates to the media's level of sensory fidelity, which must be measurable and comparable (Cummings, & Bailenson, 2015; Bowman & McMahan, 2007; Slater & Wilbur, 1997). Some examples of immersive features are field of view, body tracking, frame rate, sound quality, and realism (Cummings & Bailenson, 2015; Bowman & McMahan, 2007; Slater & Wilbur, 1997).

A key component to defining immersion is the ability to block out the physical world and replace it with other sensory stimuli. In contrast, the experience of immersion refers to the psychological involvement a person can have with the technology. For example, a person can feel greater immersion reading a novel, a form of media that has low sensory fidelity (compared to a television screen) that has greater visual sensory feedback. Users can interact with a media content differently based on the systems level of immersion. For instance, looking around a virtual plaza can occur through the movement of a joystick (lower tracking immersion) or by head movement (higher tracking immersion).

Technologically, virtual reality is defined by the tracking and rendering of a system (Blascovich & Bailenson, 2011). Tracking captures the movement of the user (pushing a button, movement of the wrist) and renders or updates the virtual world based on that tracked movement (a character jumps). Actions are tracked and rendered using translations (movement along x-,y-, z-axis) and/or orientation (pitch, roll, and yaw). According to Slater (2009), the display and the interactive nature of IVR cannot be separated thus the need to define IVR by its tracking and rendering capabilities.

Illustrated in the aforementioned meta-analysis by Cummings and Bailenson (2015), two of the three features of immersion that had the greatest impact on presence were related to vision (i.e. stereoscopic vision and field of view). The ability for IVR to influence attitudes and its behaviors could be due to its psychological effect on people. Then in a psychological sense virtual reality can be defined as an environment (real or simulated) in which the perceiver experiences it as real (Blascovich & Bailenson, 2011; Steuer, 1995).

Immersive virtual reality is a specific type of virtual reality. According to Slater (2009) IVR provides "a fundamentally different type of experience, with its own unique conventions and possibilities, a medium in which people respond with their whole bodies, treating what they perceive as real" (Slater, 2009, p. 3549). IVR can be defined as a system that has the objective technological capabilities that block out the physical world that provides rich sensory fidelity, and also one in which users feel psychologically located in the simulated environment and/or experiencing it as real.

Two types of technology commonly used to create IVR are Cave Automatic Virtual Environments (CAVEs) or head-mounted displays (HMDs). They can provide body tracking, stereoscopic vision, and a field of view similar to normal human sight. A CAVE is a specially designed room in which the walls, ceiling, and/or floor are covered with a screen that projects virtual images (Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992). Three-dimensional views are created by either donning special eyewear such as stereoscopic glasses or the use of autostereoscopic screens. In highly immersive CAVEs, the user is completely surrounded by the virtual environment (via the walls, ceiling and floor). Although a CAVE has many immersive qualities, it does not completely block out the physical world. In a CAVE, the user cannot change how his or her body is represented in the virtual space.

A head-mounted display (HMD) is a virtual reality headset that provides high levels of immersion similar to a CAVE, but with the added benefit of completely blocking out the physical world, including the user's body. While in an HMD, users can look down and see their digital representation as a different sex, ethnicity, or body size; they can even embody an animal or an imaginary creature. Research shows that the types of bodies people take on while in IVR impact their attitudes and behaviors, such eating habits and environmental behaviors (Ahn, Bailenson, & Park, 2014; Fox, Bailenson, & Binney, 2009).

Research with IVR and Children

The following section provides a content analysis of empirical research utilizing IVR (via an HMD or CAVE) that include children as part of the study's sample (anyone under the age of 18-years of age). Each article was evaluated on three criteria: 1) the study utilized IVR technology such as an HMD and/ or CAVE; 2) tested IVR with at least one child participant; and 3) it was an empirical study. Table 1(Appendix) presents an overview of each study.

Criteria for Study Selection

HMDs were defined as virtual reality headsets that covered both of participants' eyes, and blocked out the physical world from direct view, including devices with either mono- or stereoscopic vision. Studies that overlaid digital content or images onto the physical world were considered augmented reality, and were excluded. A CAVE was considered IVR when the screens encompassed participants view, providing peripheral views of the virtual world. For example both a room with projection screen on three of the walls and a dome-like structure that wrapped around the participant were included. The table and overview highlights main trends in the literature and is not necessarily exhaustive. The content analysis included empirical research that was not reported elsewhere, thus articles that summarized or reported previous literature were not included. Finally, the studies were included if they investigated IVR with at least one participant and were excluded if it was merely a description of the technology or software.

Two coders rated the data, assigning one research theme per study. The coders were trained on 10% of the studies, randomly selected from the total sample. Cohen's kappa calculated inter-coder reliability at 0.92. All data analysis and visualization were completed in R studio (Team, 2011) and used an alpha of 0.05. The final sample consisted of 57 articles.

Research Themes

Four major research themes or aims emerged from the sample of studies: IVR used for pain distraction, education, assessment or measurement, and an examination of its media effects. Each study was sorted into one of the four categories according to its main research aim, and was never listed under multiple categories. The studies consisted of both clinical and non-clinical populations, case studies, pilot studies, and full studies that examined issues that ranged from the usability of IVR as a tool to direct effects of the technology and/or content. A study was defined as clinical if the participants were clinically diagnosed with a physical or mental illness/disease, receiving direct medical treatment, or identified as non-normally developing. For example, clinical studies included children diagnosed with ADHD, children receiving cancer treatments or burn wound cleaning, and those identified as deaf/hearing impaired children.

Pain Distraction. Immersive virtual reality is a familiar fixture in the medical field, and much of the uses for IVR have been for pain distraction, typically via an HMD (see Shahrbaian et al., 2012 for a review). IVR has proven to be a successful pain management tool for a variety of medical procedures such as port access for cancer treatments (e.g. Gershon, Zimand, Pickering, Rothbaum, & Hodges, 2004; Schneider & Workman, 1999), burn wound cleaning (e.g. Das et al., 2005; Hoffman et al., 2008; Twillert, Bremer, & Faber, 2007), dental work (e.g. Aminabadi, Erfanparast, Sohrabi, Oskouie, & Naghili, 2012), and occupational or physical therapy (e.g. Hunter, Patterson, Carrougher, & Sharar, 2001; Snider, Majnemer, & Darsaklis, 2010; Sharar et al., 2007).

It has also been used to assess pain tolerance in non-clinical populations during cold pressor tasks (e.g. Dahlquist et al., 2009; Law et al., 2011).

Overall studies tend to compare the effectiveness of IVR as a pain distraction tool with usual care, other distraction tools, and non-immersive VR distractions. The literature demonstrates that IVR reduces the perception of pain more so than usual care and some other distraction techniques including non-immersive environments (e.g. games or cartoon shows). In addition, IVR has been effective even in cases with minimal interactivity with the content (e.g. Dahlquist et al., 2007; Dahlquist et al., 2009; Law et al., 2011; Reger et al., 2003) suggesting that there are unique qualities to fully immersive content.

Education. IVR has been utilized as an educational tool for a variety of topics. Teens have donned HMDs to learn about the health risks of smoking (Nemire, Beil, & Swan, 1999), and children have interacted with CAVE environments to learn about fire safety (Smith & Ericson, 2009) and pedestrian safety (McComas, MacKay, & Pivik, 2002). Immersive virtual reality technologies have been created to facilitate conceptual learning for environmental processes that are challenging to visualize, impossible to view or too dangerous to experience in the physical world. Johnson, Moher, Ohlsson and Bililngham (1999) used IVR to teach children about the earth being round while Roussou, Oliver, and Slater (2006) used it as a tool to visualize the meaning of fractions. Through the unique features of immersive technologies, children have embodied a young gorilla in a zoo habitat to learn about the behaviors and social interactions of other gorillas (Allison & Hodges, 2000; Allison, Wills, Hodges, & Wineman, 1997).

IVR has also been used for skill building and cognitive training (i.e. providing life skills training such as crossing the street for deaf and hearing-impaired children; Vogel et al., 2006). Other training has included cognitive or attention training for deaf or hard of hearing children (Passing & Eden, 2000a; Passing & Eden, 2000b), for children with ADHD (Cho et al. 2002), and with Autism Spectrum Disorder (Jarrold et al., 2013). There have been mixed results for IVR as an effective learning tool, varying widely with the content and its use cases. Much of the research has demonstrated its feasibility as a learning tool that increases children's enjoyment of and motivation for learning.

Assessment. For its unique ability to track nonverbal behavior (i.e. eye gaze, body position or movement), researchers have used IVR as a nonintrusive measurement tool. IVR technology collects thousands of data points of what the user is doing at any given point, reducing a reliance on self-report measures. For example, researchers created a virtual classroom to assess for ADHD by utilizing IVR's unique attentional features (e.g. Bioulac et al., 2012; Parsons, Bowerly, & Rizzo, 2007; Pollak et al., 2009). IVR's ability to track eye gaze has been used to identify and understand the cognitive abilities of children with brain injuries (Gilboa et al., 2015). In non-clinical samples, IVR has measured children's street crossing behaviors to improve their pedestrian safety (e.g. Babu et al., 2011; Morrongiello, Corbett, Milanovic, & Beer, 2015; Simpson, Johnston, & Richardson, 2003), and utilized IVR as a tool to examine postural stance (Lee, Cherng, & Lin, 2004).

Media Effects. Few studies specifically examined the media effects of IVR on child development. The existing studies have tested IVR's physiologically effect on the ocular system, and psychologically impact on children's memory. Kousulin, Ames, and

McBrien (2009) examined the 'short term' use of IVR on children's visual system, comparing a binocular viewer to an HDTV display. Examining the psychological effects of IVR, Segovia and Bailenson (2009) explored the affect of an IVR experience on memories among young children and compared it to other types of immersive and non-immersive experiences (i.e. mental imagery, verbal narrative). With so few studies to rely on, the developmental media effects largely remain unknown.

Content Analysis Results

Research on IVR and children has investigated IVR for pain distraction, education, training, and assessment tools, with only a few studies delving into specific issues related to child development (Figure 1). The majority of the research has focused on IVR as a pain distraction tool (38.6%) and for educational purposes (33.33%). IVR as for assessment was the next largest theme at 22.81%, and studies that investigated the media effects of IVR came to only 5.3% of the sample.

Within each research theme, the studies examined children within clinical and non-clinical populations. More than half of the research (56.14%) included clinical samples (i.e. cancer and burn patients, children with ADHD, or Autism Spectrum Disorder). The percentage increases to 63.1% when studies that have a clinical purpose but only include normally developing children (i.e. pain distraction during a cold pressor task).

The sample sizes in the literature range from one child participant to over 100 children (Figure 2). Nearly half (45.61%) of the studies consisted of case or pilot studies (20 or less participants for between subject designs or indicated by authors; Table 1). Typically, these smaller studies focused on the feasibility or utility of the IVR (i.e.

enjoyment, usability; Table 1). The studies also varied in the age range within any given study. The minimum age range of all the studies is 0 (i.e. case study or all the same age) and the maximum age range of 59. The mean age range is 8.58 years with a standard deviation of 11.52 years.

Discussion

Decades work of research regarding immersive virtual reality and adults exists; however, there are a limited in the number of empirical research related to children. An examination of the literature shows four common research themes emerged: pain distraction, education, assessment, and media effects. These research aims have included both clinical and non-clinical populations.

Results from this analysis of the field, show that nearly half of what the community knows about children and IVR is based on pilot or case studies. Perhaps related to cost and access to the technology, many of the studies have small sample sizes relative to the number of age groups within that sample. For example, Hoffman and colleagues (2008) examined the use of IVR for pain management during wound cleaning among eleven participants ages 9 to 40 years old. While this study like many other studies demonstrate the utility of IVR as a pain distraction tool, little can be said about how this effect may relate to age. The underlying assumption in much of the research is that people process and respond to IVR similarly regardless of age. This is an issue for identifying trends or differences according to skills associated with age.

Even more evident in the literature, is the dearth in research with young children, specifically those under the age of seven. Although new technologies tend to be developed for adults and older adolescents, young children often get access and experience with them. With growth of virtual reality in the consumer market, it will be important to understand the uses and effects of IVR among young children to inform regulatory guidelines for access and content development. Finally, over 60% of the studies focused on clinical populations and clinical uses. With little research dedicated to addressing developmental issues, and among nonclinical populations, questions linger regarding the physical, social, and psychological relationship between tpyical human development and IVR.

Issues of Child Development to Consider

IVR can create compelling scenarios with salient sensory stimuli. But what does this mean for a young child's everyday experience? Cognitive skills related to emotional and behavioral regulation could influence how children experience IVR as real. How well do children process media that blocks out the physical world completely, and how could this influence their understanding of the virtual and physical world? Young children in particular, are developing executive function skills (i.e., inhibitory control, working memory, cognitive flexibility), and may have trouble realizing that the physical world still exists. Some research suggests that age influences how virtual content is experienced, with young children experiencing virtual worlds as more real than their older counterparts (Baumgartner, et al., 2008; Baumgartner, Valko, Esslen, a& Jänke, 2006; Sharar et al., 2007). The brain processing IVR as real, could explain why IVR acts as an effective distraction tool among children; however, this is also important to consider for physical safety. Young children may struggle to be remember where they are located in a physical space and run into a wall. It may be important to have close parental supervision for certain scenarios or content.

Children can interact in IVR environments in a variety of ways. They can see and control an avatar from the first person or from the third person. Typically, an avatar is a digital representation that the user controls in real time. Today children can now see a photorealistic image of themselves engaging in behaviors that they never done (i.e. virtual doppelgangers; Fox, Bailenson, & Binney, 2009). Research with adults has shown that seeing oneself engage in activities in IVR can catalyze self-efficacy and behavior change such as reducing paper waste or increasing physical activity (Blascovich & Bailenson, 2011). In contrast, the wrong content could persuade children in less positive directions. In addition to avatars, embodied virtual agents can influence children such as their decision-making processes. For instance, young children in a study by Claxton and Ponton (2013) utilized information from a virtual character (that acted socially contingent) as much as a live person directly in from of them. It will be important to understand how children process their own digital representation and other virtual characters when in a virtual environment that is fully immersive.

Future Directions

With IVR technology becoming more accessible and more lightweight, the field of children and media's research can expand. Future research could examine how the unique features of immersive virtual reality or immersive technologies relate to human development. Little is know about the similarities and/or differences between IVR and other types of media. Scholars could examine the ways in which children socially and behaviorally respond in the virtual and physical worlds after being exposed to a character that seems close enough to touch. Or perhaps the effects of a character that varies in size. In addition, certain ages may respond to virtual characters differently. For instance, older adolescents may be particularly sensitive to social exclusion even in virtual simulations due to brain development (Blakemore & Mills, 2014).

In addition, to interacting with other characters in virtual environments, research could examine how virtual embodiment relates to development. Virtual embodiment literature demonstrates that adults can map their body schema onto their avatars altering their psychology (e.g. increased confidence, Yee, Bailenson, & Ducheneaut, 2009) and physiology (e.g. change in skin temperature; Salomon, Lim, Pfeiffer, Gassert, & Blanke, 2013). What does it mean for a child to embody an avatar that is completely different than their physical self? With so little in the field, there are many topics of research to consider in understanding children's experience of IVR.

Conclusion

The consumer industry of IVR technology is growing, and virtual reality is becoming more integrated into every day experiences. One example is the New York Times sending millions of cardboard HMDs to its Sunday subscribers, changing how its readers experienced news (Somaiya, 2015; Wohlsen, 2015). With this simple initiative by a newspaper, children of all ages most likely saw or experienced virtual reality for the first time, pushing the boundaries of what media use mean for the next generation of users, and even what it could mean to be a kid.

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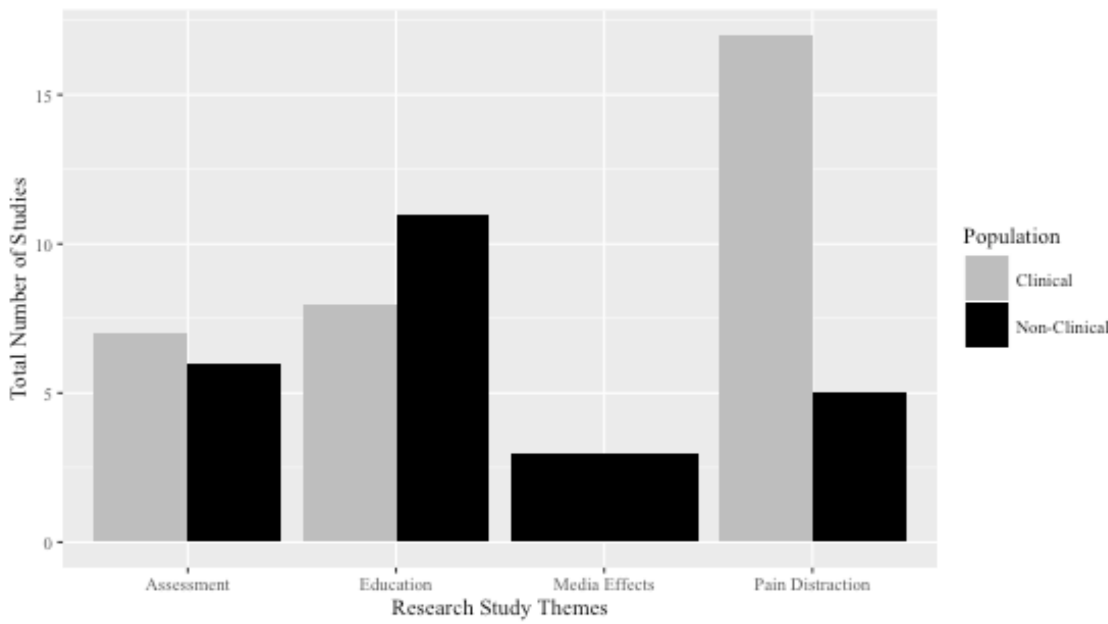

Fig. 1. A bar graph illustrating the number of studies in each research theme and the number that included of clinical and non-clinical populations.

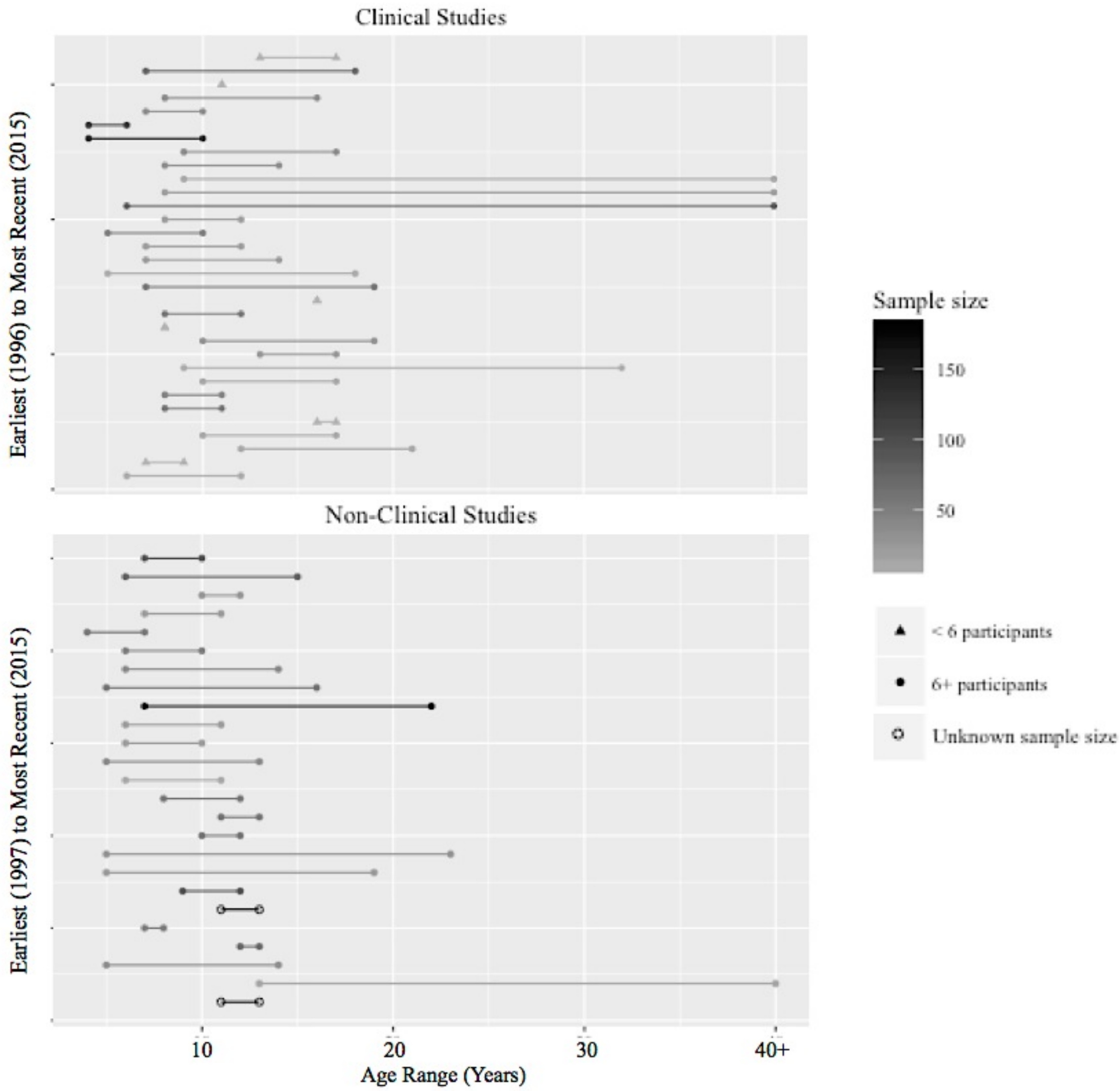

Fig. 2. The graph illustrates the age range within each study and the sample size. The age range is the difference in years between the age of the youngest and oldest participant in the sample. The studies are sorted according to their publication year. Darker color indicates more participants in the sample. Four studies included age ranges of forty years of more.