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Customized gaming system engages young children in reaching and balance training

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Abstract

Purpose: Trunk stability, an important prerequisite for many activities of daily living, can be impaired in children with movement disorders. Current treatment options can be costly and fail to fully engage young participants. We developed an affordable, smart screen-based intervention and tested if it engages young children in physical therapy goal driven exercises.

Methods: Here we describe the ADAPT system, Aiding Distanced and Accessible Physical Therapy, which is a large touch-interactive device with customizable games. One such game, "Bubble Popper," encourages high repetitions of weight shifts, reaching, and balance training as the participant pops bubbles in sitting, kneeling, or standing positions.

Results: Sixteen participants aged 2–18 years were tested during physical therapy sessions. The number of screen touches and length of game play indicate high participant engagement. In trials lasting less than 3 min, on average, older participants (12–18 years) made 159 screen touches per trial while the younger participants (2–7 years) made 97. In a 30-min session, on average, older participants actively played the game for 12.49 min while younger participants played for 11.22 min.

Conclusion: The ADAPT system is a feasible means to engage young participants in reaching and balance training during physical therapy.

Keywords

Pediatric rehabilitation, engagement, compliance, balance training, gamification

Clinical background

Motor disabilities are the most common functional disability in the United States, affecting nearly 14% of the nation's population.[1] Motor disabilities hinder a person's ability to complete everyday tasks.[1] Poor trunk control caused by motor disabilities affect balance control when sitting, standing, and walking.[2] These deficits, when occurring early in childhood, cause delays in achieving developmental milestones leading to long-term physiological and psychological impairments and reduced quality of life.[3] Early physical therapy (before age five) may minimize these delays but can be hindered by lack of long-term adherence.[4,5]

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Consistent adherence to a long-term physical therapy regimen promotes positive adaptations through neuroplasticity.[6] Low adherence has often been attributed to low levels of engagement.[7] Thus, improving engagement may be key to increasing adherence and reducing the effects of motor deficits. Virtual reality (VR) is thought to be an effective solution for engaging physical therapy for adults and older children, but is unfortunately unsuitable for young children.[8,9] Young children require specific customizable gaming appropriate for their developmental age to engage optimally.

The Self-Determination Theory (SDT) is one framework defining key tenets of engagement in pediatric rehabilitation.[10] SDT theorizes that growth and well-being depend upon the fulfilment of three psychological needs: autonomy, competence, and relatedness. In rehabilitation, autonomy is given through authentic choice, competence through perceived excellence, and relatedness through meaningful connections and interactions. Engagement is raised by meeting these needs which improves adherence both in-session and long term and leads to better patient outcomes.

Here we describe the development and implementation of a VR-mimetic, smart screen-based intervention suitable for clinic and home use to address the need for greater engagement of young children in physical therapy goal driven exercises. We propose that a therapy solution which specifically aims to improve patient engagement during the session has strong potential to result in improved physical outcomes.

Materials and methods

Participants

Our objective was to engage young children in therapy. We enrolled children aged 2–18 years to compare younger to older children. Participants were recruited from Kennedy Krieger Institute in Baltimore, Maryland, USA. Eligible inpatients and outpatients were selected by physical therapists (PTs) based on the appropriateness of the game for their treatment sessions. All participants or a parent/legal guardian gave informed and written consent to participate prior to study sessions according to the Johns Hopkins Medicine Institutional Review Board.

The ADAPT system

We developed the Aiding Distanced and Accessible Physical Therapy (ADAPT) system based on discussion between engineers and pediatric PTs. We identified a need for a system to engage young children in greater dosing of therapeutic activities, similar to that which can be accomplished for older individuals using a VR system. Review of existing technologies showed the lack of a VR system suitable for young children that is easy to set up and provides quantitative information. We achieve this by gamifying therapeutic exercises that promote balance control during reaching. Our system administers games requiring the child to physically interact with the touch-interactive display in ways that are clinically relevant. For example, to strengthen the trunk, children maintain balance while reaching far from midline in the game (Figure 1(a)). At the end of a session, the ADAPT system produces a statistical report of performance metrics.

Figure 1(a) shows the design of the ADAPT system. The prototype evolved based on feedback from both PTs and children who used the system. The current design includes a large 55-inch TV mounted on a height-adjustable, rolling TV stand with a clear acrylic sheet protecting the screen. An infrared (IR) frame attached to the sheet registers the user's input. The equipment cost was $735 excluding the laptop computer.

We created games for the ADAPT system using Unity® that promote patient engagement by upholding the core tenets of the SDT model. The Bubble Popper game promotes autonomy by providing children the ability to customize gameplay with background and in-game reward category (e.g. animals, superheroes, etc) selections. The intuitive user interface allows children to participate in navigating through the game further bolstering autonomy. Competence is promoted through adjustable difficulty settings (e.g. bubble size and speed, and range of play area), changeable before and during the game allowing gameplay that accommodates the user's abilities (Figure 1(b)). At the end of the game, the participant is shown a congratulatory screen reading "You popped bubbles!". The fixed end screen ensures participants will not be discouraged by a lower score if they are given a particularly difficult task. This way, the participant feels pleased at their performance and is encouraged to play again, no matter their score. Finally, the Bubble Popper game fosters relatedness through its visually stimulating, game-like design creating a fun experience.

During the Bubble Popper game, bubbles spawn at random locations throughout the screen. Therapists are able to change the pattern of bubble spawning by altering game modes. Setting examples include "Obstacle" mode which obstructs portions of the screen and "Quadrant" mode, which spawns bubbles sequentially across quadrants. Bubbles move around the screen at a pace decided by the therapist. When the child touches a bubble, the bubble pops and a "reward" appears. Participants are not penalized for missing any bubbles. The play time is preset by the therapist and a motivational message appears on the screen at the end.

The ADAPT system not only engages patients but also aids PTs. Therapists and parents can easily tailor the game for the child's specific therapeutic needs. The ADAPT system returns an encrypted output file of game data after each trial. These files can be uploaded to a website for

Figure 1. (a). Participant playing the Bubble Popper game. (b). Two screenshots of the Bubble Popper personalization screen. The top image shows adjustments for the bubble size and speed, and an option to set how long the trial will be played. The bottom image shows the various theme options available to the user and the shape of the bubble that will appear.

analysis and generation of a PDF report. To preserve participant privacy, the files are 2-factor encrypted and destroyed during the process, ensuring that the files are never stored remotely. The report includes quantitative engagement metrics for evaluating a child's performance. The feedback provided by the data analysis reports allows therapists to track change over time in a clear, simple way.

Study design/testing procedure

Participants completed at least one 30-min physical therapy session that included playing the Bubble Popper game. The therapist oriented the participant by demonstrating the system and the child selected their preferred in-game rewards. The PT administered each session, guiding the participant through a series of trials with different game modes and difficulty settings. The PT increased the level of difficulty during and across sessions to increase the movement challenge and prevent boredom. During the trials, the system recorded in-game performance data and the PT documented notes on the participant's subjective performance.

Outcome measures

Participant characteristics

Participant characteristics including age, sex, disability level, and cognition were obtained from chart review and PT assessment, and are displayed in Tables 1 and 2.

Therapist reported outcomes of engagement (qualitative)

The participant's therapist completed pre- and post-test engagement questionnaires. We report the mean and standard deviation (SD) of these tests.

Pretest. The Hopkins Rehabilitation Engagement Rating Scale (HRERS) establishes a baseline measure of the participant's engagement during traditional therapy. The HRERS evaluates five items on a 6 level Likert scale from 1 (never) to 6 (always). The HRERS has been shown to have an inter-rater reliability of 0.73 and an internal consistency of 0.91.[11]

Post-test. We developed an engagement questionnaire to assess the PTs' and participants' subjective experience with the ADAPT system in reference to the participants' behavior during traditional therapy sessions.[12] The post-test evaluates nine items on a 5-level Likert scale from 1 (strongly disagree) to 5 (strongly agree). This questionnaire asks the therapist to assess the participant's performance, the participant's engagement, and whether the ADAPT system meets their therapy needs.

Performance metrics (quantitative)

The ADAPT system provides performance statistics on game play. Key outcome measures that demonstrate engagement include the total play time (minutes), the number

Table 1. Participant demographics.

ID	Age (years)	Sex (M/F)	Setting	Diagnosis	Assist needed	Play Position(s)
1	12	M	IP	CP (spastic diplegic) Post-ortho surgery	Walker	Standing
2	6	M	IP	CP	Therapist assistance	Standing
3	3	F	OP	Ataxia CACNA1A	Therapist assistance	Sitting
4	5	F	IP	CP (spastic diplegic) Post-ortho surgery	Therapist assistance	Standing and stepping
5	14	F	IP	CRPS	Bioness, bolster or bench	Standing
6	2	F	IP	CP (spastic diplegic) Post-ortho surgery	Stander	Standing
	3	F	OP	CP (spastic diplegic) Post-ortho surgery	Therapist assistance	Standing and kneeling
7	7	F	IP	Ataxia Cerebellar AVM	Therapist assistance	Standing on compliant surface
8	3	F	OP	Paroxysmal torticollis Migraine	Therapist assistance	Standing and stepping
9	5	M	IP	CP (spastic diplegic) Post-ortho surgery	Therapist assistance	Standing and stepping
10	13	M	IP	CP (spastic diplegic) Post-ortho surgery	Sitting on reverse walker and bench, standing with walker	Sitting and standing
11	18	F	IP	CRPS	Therapist assistance	Kneeling and sitting on compliant surface
12	4	F	OP	Left hemimegalencephaly History of left hemispherectomy	Hand on therapy ball or quad cane	Standing
13	14	F	IP	Functional paraplegia	Therapist assistance	Standing
14	4	M	OP	CP (left spastic hemiplegia)	Therapist assistance	Standing on compliant surface
15	3	F	OP	Spina bifida	UE support and therapist assistance	Prone, sitting on compliant surface, standing
16	14	M	IP	CP (spastic quadriplegia)	Bilateral AFOs, walker (unilateral and bilateral support)	Standing

Note: Participant 6 was tested in both the inpatient and outpatient settings.
Abbreviations: AFO, ankle foot orthosis; AVM, arteriovenous malformation; CACNA1A, calcium voltage-gated channel subunit alpha1 A gene mutation; CP, cerebral palsy; CRPS, Complex regional pain syndrome; F, female; IP, inpatient; M, male; OP, outpatient; UE, upper extremity.

Table 2. Summary participant demographics.

	Under 8 years old	Over 10 years old
Total N	10	6
Sex (male/female)	3/7	4/2
Inpatient setting	5*	6
Outpatient setting	5	0
Cerebral palsy	5	3
Other diagnosis	5	3

* one patient was tested first in the inpatient and then in the outpatient setting. This participant is counted as part of the inpatient total.

of touches, the inter-touch interval (ITI), and the pop-to-touch ratio. The ITI is the amount of time between touches. The pop-to-touch ratio is the number of touches that resulted in a popped bubble divided by the number of touches to the screen. We define total play time as our primary quantitative engagement metric, as an unengaged participant would stop playing the game sooner than a more engaged participant.

Results

The study sample included eight participants with cerebral palsy, two with complex regional pain syndrome, two with ataxia, one with spina bifida, and three with other movement disorders, for a total of 16 participants (6 males:10 females). Participants had a range of disabilities from requiring trunk support in sitting to supervision for dynamic standing activities. Nine PTs used the game with the participants in a variety of treatment conditions including prone over a therapy ball, quadruped, tall kneeling, sitting, and standing.

The average engagement pretest score was high (26 ± 4 out of 30) demonstrating that participants were highly engaged during traditional therapy. The engagement post-

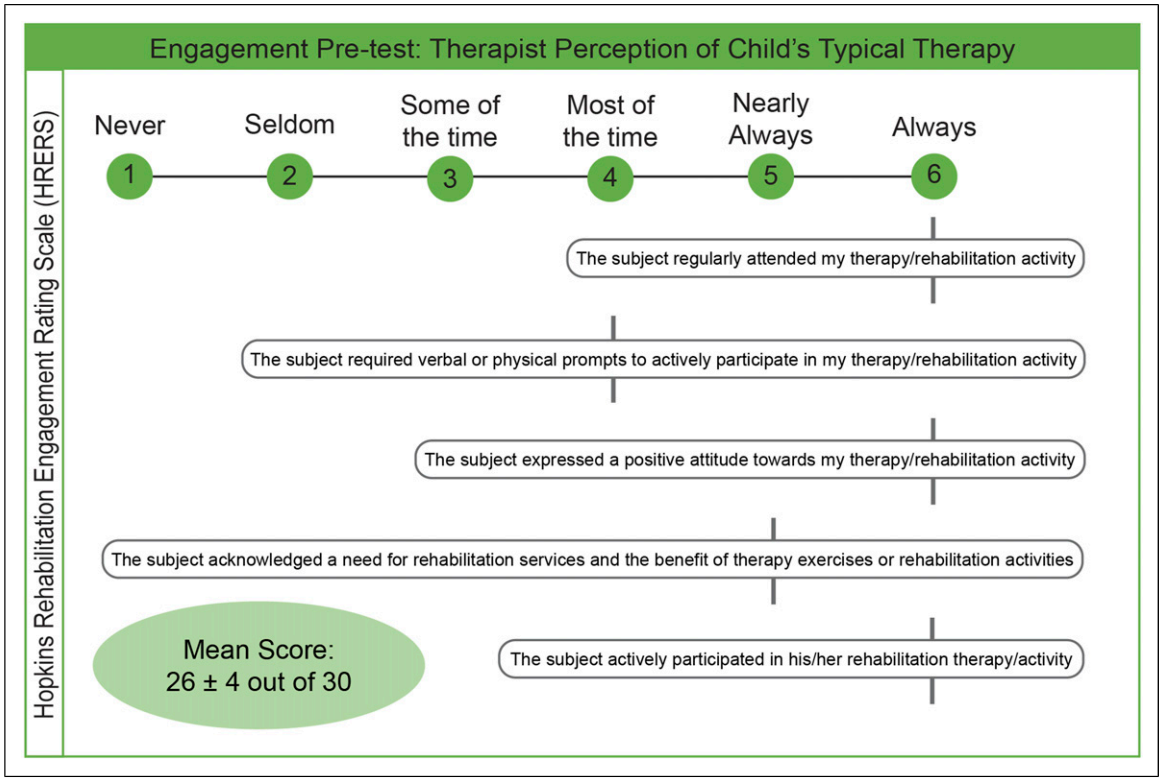

Figure 2. Pre-test engagement survey. Prior to using the game with a participant, therapists were asked to rate the participant's typical therapy performance using the five questions from the Hopkins Rehabilitation Engagement Rating Scale (HRERS). Average therapist responses shown for each question. A total of 3 therapists were surveyed.

test indicated therapists found the Bubble Popper game and the ADAPT system effective at engaging participants compared to typical therapeutic activities (average score 39 ± 5 out of 45). Figures 2 and 3 provide details of the engagement pre- and post-test results.

A total of 176 trials were recorded ranging in length from 0.5 to 3 min. The average number of trials for a single participant was 9 ± 5 (range 3–19). The average number of trials per session was 6.1 ± 2.5 (range 2–11).

Younger participants (age 2–7 years) engaged in a similar duration of therapeutic movement as the older participants (Figures 4(a) and (b)). Both younger and older participants performed up to 200 reaches during game play, with some participants reaching up to 300 times. Younger participants played the game for nearly the same amount of time as older participants (younger: 10.7 ± 3.6 min, older: 13.3 ± 5.6 min).

Game output includes the number, timing, and location of all screen touches regardless of accurate bubble pops to assess the treatment dose and participant performance. Across ages, participants showed similar screen touch frequency (ITI, Figure 4(c)) though a few of the youngest showed slower touches. All participants showed similar successful performance in the pop-to-touch ratio (Figure 4(d)) quantitatively indicating that the game is customizable enough to be both challenging and rewarding enough to motivate children of varying capability to make accurate touches. These results also show that the ADAPT system fulfils the core tenets of the SDT model. As can be seen by the ITI and the pop-to-touch ratio data, participants made clear, motivated attempts to pop the bubbles.

Figure 4(e) is a spatio-temporal plot of the locations of touches of a single trial, allowing the visual qualitative analysis of the ability of the ADAPT system to engage participants in reaching and balance training. Throughout the trial, the participant shifted from making touches in the center-left of the screen to the center-upper right of the screen and eventually to the bottom-right of the screen.

Discussion

Current physical therapy interventions for motor disabilities are often limited in achieving desired results due to the challenges in fully engaging young children in directed activities. Traditional therapy is both safe for young children and has been shown to be effective, but often fails to effectively engage young children. Specialized garments are safe for children but fail to train the muscles, decrease independence of children, and are inconvenient to use.[13]

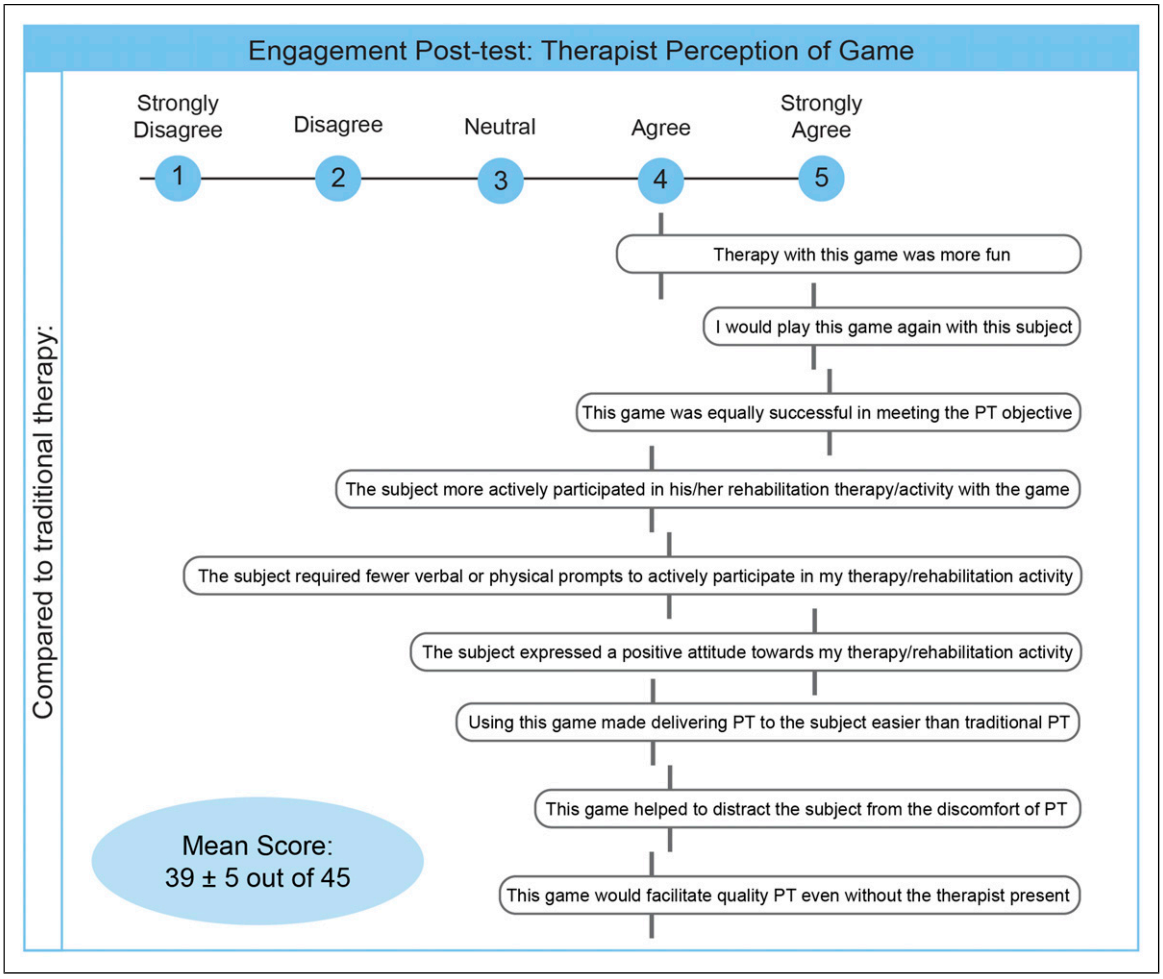

Figure 3. Post-test engagement survey. After using the game with a participant, therapists were asked to rate the participant's engagement in therapy with the game compared to typical therapy using a nine question survey. Average therapist responses shown for each question. A total of 3 therapists were surveyed.

One of the most recent innovations in physical therapy with a high potential for engagement is virtual reality. Unfortunately, current designs for this technology prevent it from being used with young children.[9] Engineers and rehabilitation professionals collaborated to develop the ADAPT system with a design centered around the three core tenets of the Self-Determination Theory to fulfill the need for engaging rehabilitation tools and address the shortcomings of existing solutions. Qualitative and quantitative assessments demonstrate its success in engaging young participants in reaching and balance training.

Qualitatively, PTs report that therapy with the ADAPT system is as engaging as other delivery methods. Therapists agreed with the statements that the game made the delivery of therapy easier, that therapy with the game was more fun, and that the game was equally effective in meeting the therapy goals. Additionally, therapists affirmed that they would incorporate the game in a future therapy session.

Quantitatively, the ADAPT system provides a number of metrics that can be used to measure therapy dose in young children with more ease and specificity than by other means. Young children demonstrated continuous engagement in a focused reaching activity while using the ADAPT system. Similar average game play times between younger and older participants highlight that both age groups were willing to engage in the game for similar amounts of time and younger participants did not opt to stop a session early.

The ADAPT system addresses several of the questions to developers of rehabilitation technology made by Sulzer and Karfeld-Sulzer.[14] Specifically, the ADAPT system encourages active participation of the child, requires minimal setup and expertise to run, and facilitates therapy goals. During the design process, engineers consulted with PTs for insights on treating motor disabilities, standard engagement strategies during therapy, and meaningful measurements of performance. With this feedback, engineers designed the ADAPT system with flexibility to facilitate different types

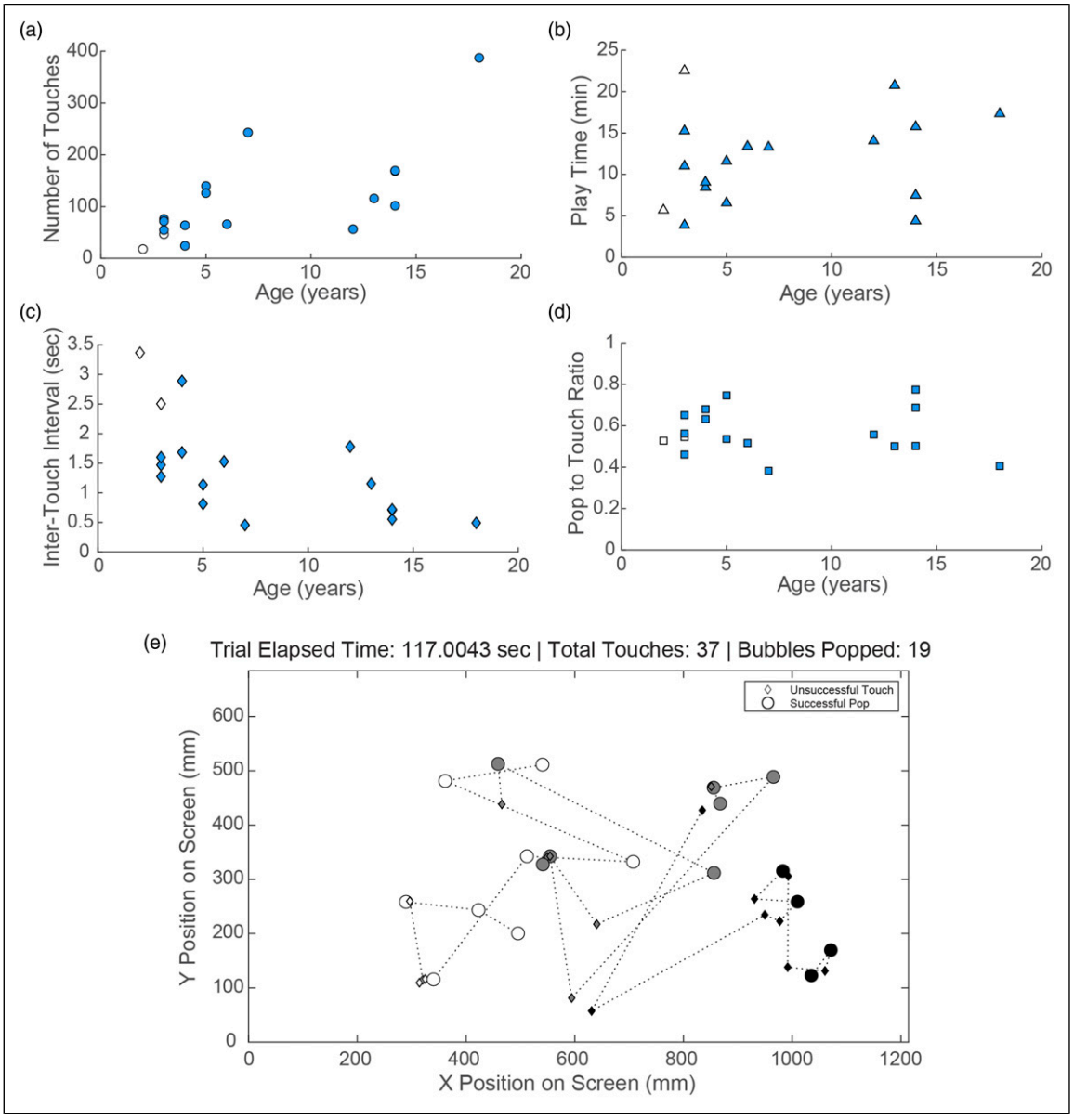

Figure 4. (a). Average number of touches made in a trial by each participant. In A-D, two of the markers are not filled in to indicate that one participant was tested at two time points separated by 6 months at ages 2 and 3 years old. (b). Average total time played per trial by each participant across their testing sessions. (c). Average inter-touch interval for each participant. (d). Average pop-to-touch ratio for each participant. (e). A spatial plot of the touches made by a participant during a single session. A circle marker indicates a successful pop, and a diamond indicates an unsuccessful touch. The touches are divided into three segments to demonstrate the area on the screen that was touched as the trial progressed. Touches 1–12 are indicated in white, 13–25 are indicated in grey, and 26–37 are indicated in black.

of exercises and in a range of positions. The design process of the ADAPT system affirms the importance of multi-disciplinary collaboration to address rehabilitation needs.

Furthermore, the ADAPT system has received positive and encouraging feedback at several presentations and conferences.[15–17] Most notably, the ADAPT system was presented at the American Physical Therapy Association's 2022 Combined Sections Meeting, a conference that allowed the ADAPT system to garner interest at the national level.[15]

Limitations

The game settings and testing conditions were not uniform across trials. Therapists tailored each game to meet a participant's particular therapy goals. The screen size was

changed part way through data collection. The initial prototype for the ADAPT system that used rear projection techniques with a custom-made screen (122 cm × 163 cm) was changed to a standard TV screen (123 cm × 76 cm) to improve device portability and reproducibility. Because therapists had routinely reduced the initial prototype play area, the screen size change had a minimal effect on study results. Game variation is one of the ADAPT system's main strengths, enabling autonomous customization for therapists and participants alike. Therefore, while not consistent between participants, varying game settings across participants allows us to evaluate ADAPT in a realistic therapeutic setting.

Future directions

We plan to develop additional games for the ADAPT system that incorporate a cognitive component (i.e. card-matching). PTs are interested in an adaptive and responsive game algorithm based on a child's performance. Ongoing research targets children ages 2–10 years old with balance impairments, in a movement comparison study of ADAPT game play versus traditional therapy activities. The two therapy delivery mechanisms are compared via the respective dosing of weight shifts, reaches, and overall movement.

Conclusion

Engagement is an essential but challenging factor in successful therapeutic outcomes. The ADAPT system is an affordable, smart screen-based intervention that engages young children in physical therapy goal driven exercises.

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Author Contributions

SR, NM and AB conceived the project. SP, KL, JP, CS, RS, ML, SR, NM, TB, AS, AB, and JK were involved in protocol development and implementation. SP, KL, JP, ML, SR, NM, TB, and AS developed the device and software. CS, RS, and JK were involved in participant recruitment and data collection. SP, KL, JP, NH, and JK were involved in data analysis. SP and SR wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved of the final version.

Declaration of conflicting interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: SP and JK received speaker's honorarium from the American Physical Therapy Association. CS, RS, NH, AB, and JK are employees of Kennedy Krieger Institute. AB has received grants from the National Institutes of Health not directly related to this project. NH is supported by a training grant from the National Institutes of Health not directly related to this project.

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References

1. CDC. *Disability Impacts all of us infographic | CDC*. Centers for Disease Control and Prevention, 2019, https://www.cdc.gov/ncbddd/disabilityandhealth/infographic-disability-impacts-all.html (accessed 22 May 2022).
2. Van Criekinge T, Truijen S, Schröder J, et al. The effectiveness of trunk training on trunk control, sitting and standing balance and mobility post-stroke: a systematic review and meta-analysis. *Clin Rehabil* 2019; 33: 992–1002.
3. Hsieh R-L, Hsieh W-H and Lee W-C. Short-term family-centered workshop for children with developmental delays enhances family functioning and satisfaction: a prospective clinical trial. *Medicine (Baltimore)* 2016; 95: e4200.
4. Spittle A, Orton J, Anderson PJ, et al. Early developmental intervention programmes provided post hospital discharge to prevent motor and cognitive impairment in preterm infants.*Cochrane Database Syst Rev* 2015; 2015, https://www-ncbi-nlm-nih-gov.proxy1.library.jhu.edu/pmc/articles/PMC8612699/(accessed 22 May 2022).
5. Jack K, McLean SM, Moffett JK, et al. Barriers to treatment adherence in physiotherapy outpatient clinics: a systematic review. *Man Ther* 2010; 15: 220–228.
6. Johnson RW, Williams SA, Gucciardi DF, et al. Evaluating the effectiveness of home exercise programmes using an online exercise prescription tool in children with cerebral palsy: protocol for a randomised controlled trial. *BMJ Open* 2018; 8: e018316.
7. Lequerica AH, Donnell CS and Tate DG. Patient engagement in rehabilitation therapy: physical and occupational therapist impressions. *Disabil Rehabil* 2009; 31: 753–760.
8. Hoffman HG, Patterson DR and Carrougher GJ. Use of virtual reality for adjunctive treatment of adult burn pain during physical therapy: a controlled study. *Clin J Pain* 2000; 16: 244–250.

9. Gent LiveScience E. Are virtual reality headsets safe for children? *Scientific American* 2016, https://www.scientificamerican.com/article/are-virtual-reality-headsets-safe-for-children/(accessed 22 May 2022).
10. Meyns P, Roman de Mettelinge T, van der Spank J, et al. Motivation in pediatric motor rehabilitation: a systematic search of the literature using the self-determination theory as a conceptual framework. *Dev Neurorehabil* 2018; 21: 371–390.
11. Kortte KB, Falk LD, Castillo RC, et al. The hopkins rehabilitation engagement rating scale: development and psychometric properties. *Arch Phys Med Rehabil* 2007; 88: 877–884.
12. Popović MD, Kostić MD, Rodić SZ, et al. Feedback-mediated upper extremities exercise: increasing patient motivation in poststroke rehabilitation. *BioMed Res Int* 2014; 2014: 520374.
13. Nicholson JH, Morton RE, Attfield S, et al. Assessment of upper-limb function and movement in children with cerebral palsy wearing lycra garments. *Dev Med Child Neurol* 2001; 43: 384–391.
14. Sulzer J and Karfeld-Sulzer LS. Our child's TBI: a rehabilitation engineer's personal experience, technological approach, and lessons learned. *J Neuroeng Rehabil* 2021; 18: 59.
15. Krieger K. *Penny's story*. Kennedy Krieger Institute 2022, https://vimeo.com/705346521.
16. Lee K and Parise S. The ADAPT system: a novel gamification system for supplementing pediatric physical therapy treatment, 2022, https://youtu.be/PxxqOUKEv1Y.
17. Parise S, Lee K, Park J, et al. *Gamification of therapist directed exercises and automated evaluation of pediatric patient progression*. San Antonio, TX, USA: American Physical Therapy Association 2022.