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Research Article

Development of a Method to Use a Color Tracker for Motor Therapy for Individuals with Rett Syndrome

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Abstract

Background and Objectives: Rett Syndrome (RTT) is a development disorder with a known genetic origin that causes a child to lose purposeful use of their hands and develop characteristic stereotypical repetitive hand movements. Through the use of Virtual Reality (VR), the frequency, length, and intensity of therapy sessions can be enhanced, leading to improved upper extremity function.

Methods: The objective was to develop a VR system, namely VR_Color Tracker, specifically tailored for persons with RTT and designed to decrease the characteristic stereotypical repetitive hand movements and increase the use of hands in skilled function. The VR_Color Tracker was created, tested, revised, and retested through the use of a multi-level, iterative development process. Limitations such as technological restrictions and effective tracking were addressed prior to testing with a RTT participant.

Results: A feasibility investigation was carried out, a System Usability Scale (SUS) was completed with the researchers, and the system's usability was determined to be in the seventieth percentile.

Conclusions: The VR_Color Tracker is feasible to use for an individualized approach to RTT therapy, but more research is needed to determine its clinical efficacy.

Introduction

While Rett Syndrome (RTT) is not a degenerative disorder, it is a leading cause of severe cognitive deficits and developmental regression in girls and affects 1 in 10,000 female births [1]. RTT is a postnatal neuro developmental disorder caused by mutations in the gene Methyl CpG Binding Protein 2 (MECP2) [1]. MECP2 is located on the long (q) arm of the X chromosome in band 28 ("Xq28") and is essential for the normal function of mature nerve cells. Often misdiagnosed with autism or a non-specific developmental delay, these young girls have normal early development with an onset of regression, or loss of previously acquired milestones, between six and eighteen months old. At that time, there is a stagnation of skills including learning, movement, ambulation, and sensory sensations [1].

The child often loses purposeful use of her hands and soon develops characteristic stereotypical repetitive hand movements, including hand wringing, clapping, clasping, squeezing, tapping, rubbing, and mouthing [1-3]. It was found that these vigorous movements occur during 30-72% of the individual's waking hours and only stop when she is asleep. Even though functional hand use deteriorates and stereotypical hand movements are difficult to voluntarily stop, interventions are used to acquire new hand skills as well as learn how to withdraw from continuous movements for periods of time [4].

Currently, there are no treatments that specifically target all symptoms of RTT [1]. Prescriptions such as L-carnitine, Melatonin, and Folinic acid have been shown to treat some, but not all, of the symptoms of RTT [4]. Physical therapy intervention is a common treatment program in order to maintain ambulation. Occupational therapy is used to correct hand stereotypical movements, manual function, short attention spans, and sensory imbalance. In order to minimize repetitive hand mannerisms, some therapists choose to use hand restraints or soft splints that inhibit stereotypical hand gestures and help in learning basic hand skills with improvement in communication, play, and feeding skills [4,5]. Therapists have found splinting most beneficial in cases where there are skin problems secondary to repetitive hand-to-mouth behavior, where restraining the less-active hand increases control over the other hand, and where the child's social interactions are disrupted due to consistent hand movements [5]. Recently, it has been shown that therapy involving the deliberate, repetitive separation of the hands can reduce stereotypical movements, such as hand wringing, and improve functional arm use for individuals with RTT [4-6].

Virtual rehabilitation and the use of video games in a therapeutic capacity has been used for patients recovering from stroke, traumatic brain injuries, muscular dystrophy, and many other diagnoses [7]. Often times repetitive exercises become monotonous and painful. However, the use of video games during therapy allows a patient's progress, behavior, and performance to be monitored, while increasing interaction, entertainment, engagement, and motivation [7,8]. With cognitive and intentional distraction, patients are able to recover from or cope with a physical problem, while awareness of pain is blocked through the patient's active attention while playing video games [7-9]. With the ability for a more varied therapy program, therapists have noticed that participants are more willing to try movements that they were once reluctant to try as well as look forward to future computer games [7,8,10].

Due to the amount of preparation that must be done for a therapy session, the time period during which direct therapy received is reduced, resulting in only thirty to forty total movements with traditional rehabilitation [11-14]. Patients therefore are not performing an appropriate number of movements needed for neuroplastic changes underlying behavioral development during standard rehabilitation sessions [12-14]. In contrast, through the use of video games, over three hundred to four hundred movement repetitions can be made in a single therapy session, strengthening the quantity of therapy [11,17]. Through the use of repetitive, challenging movements, molecular pathways of learning and memory are stimulated, neural plasticity is enhanced, and motor system networks show improvement as the number of synapses in the brain increase [15,16]. These principles can be used by therapists to improve functional upper extremity use through the use of VR and gaming therapy with enhanced frequency, length, and intensity of sessions [16,17].

We have shown that through the use of a VR environment, Microsoft Kinect sensors, and the potential for increased repetitions, participants are able to improve motor skills and transfer those skills effectively to valuable daily activities [18-21]. A similar method was used and trialed on six girls with RTT [6]. By tracking the movements of upper extremities, participants were able to play free Internet games while learning purposeful arm movements. However, limitations included shortcomings of the Kinect sensor; specifically, the sensor was unable to detect, quantify, or measure arm movements when arms did not move laterally from the body. Often, the Kinect sensor tracked the participants' wheelchair or chair instead of the upper extremity or was unable to pick up the movement of hands when they were at midline, ultimately causing a delayed response in game play [6]. The Microsoft Kinect sensor did not differentiate the participant's skeleton when another skeleton, for example the researcher, was visible within the sensor's field of view. These interferences and technological inconsistencies limited participants' abilities to interact with the intervention and to play the video game provided during some sessions, affecting those with more severe motor symptoms to a greater extent [6]. Further, the movement direction problems were not present in our prior work with other disabilities [20,21].

To ensure accessibility of this intervention to all individuals with RTT, even to those with more severe symptoms, we investigated the use of other motion sensing devices besides the Microsoft Kinect sensor to monitor the motion of the individuals. The purpose of this study was to investigate the feasibility of using a color tracker as a method of monitoring the hand and arm motion of individuals with RTT to permit them to play video games as a modality for enhancing motor control.

Materials and Methods

Hardware

The VR_ColorTracker system consists of custom software developed within MATLAB (R2014b), free Internet video games or videos, a computer, a webcam, a large computer monitor or TV, and colored markers or bracelets. The webcam is connected to a Windows computer compatible with MATLAB.

MATLAB Software

The custom MATLAB software is able to: (1) track a participant's hands through the use of specific color thresholds; (2) monitor the distance between the participant's hands; (3) allow the researcher to designate the specific distance that the participant's hands must reach; (4) identify when a researcher-specified distance threshold is achieved; and then (5) activate a specific keyboard stroke/mouse movement. The separation of the hands in different, customizable directions and displacements was chosen as the primary motion for VR_ColorTracker because this movement has shown promise for decreasing the repetitive, stereotypical hand movements exhibited by those with RTT [6]. The specific keyboard stroke/mouse movement permits the individual to play a video game using this movement and supplies positive reinforcement.

Through the use of a webcam, the software is able to quantify the distance between the participant's two hands through the use of color tracking. The software created tracks specific colors in live video and is based on the color feature of each pixel. Through the use of the additive RGB color model, a three dimensional vector is created to describe the color feature (red, green, blue or RGB) of each pixel. Image subtraction is first used to highlight the basic color of interest within the image. Then, the use of thresholding creates binary masks by replacing an image with a black pixel if the image intensity is less than the fixed constant threshold specified, or with a white pixel if the image intensity is greater than that constant. By specifying a threshold between 0 and 1, a specific hue can be identified, allowing only specific colors to be tracked by the VR_Color Tracker. Thresholds have been established and tested with markers in the following colors: red, neon green, blue, magenta, and yellow. The combination of image subtraction, thresholding, and binary masking allows for the separation of targeted and background pixels, thus allowing for the real-time tracking of specific colored objects in a live image.

The participant is fitted with two different markers or bracelets, each placed on the participant's wrists or on areas of the hands facing the webcam. These markers match the specific threshold colors the VR_ColorTracker is able to identify. Through the use of specific color thresholds, only the trackers on the participant's hands are processed and therefore more accurate tracking can be used.

The webcam is also used to determine the distance between the participant's hands. The software monitors the distance, in pixels, between two markers as viewed by the webcam based on the threshold and movement selected by the researcher. The VR Color Tracker uses a built in MATLAB function that identifies the size and resolution of the screen. From those two values, the screen pixels per inch is

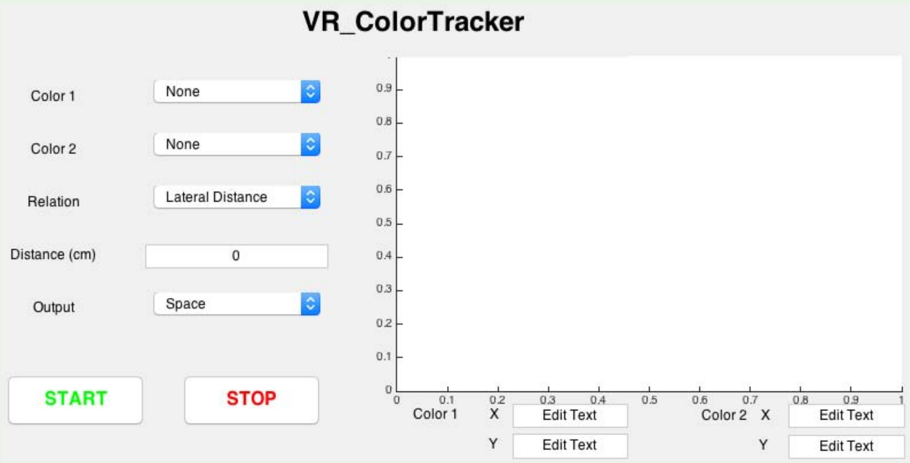

Figure 1: Graphical User Interface (GUI) for the VR_ColorTracker.

calculated. The distance in pixels is divided by the screen pixels per inch of computer display to calculate the distance in real world units.

The use of a Graphical User Interface (GUI) provides point-and-click management, creating an efficient, user-friendly experience for researchers. As shown in figure 1, the researcher is able to identify the color markers the participant is using, select the relation as horizontal or vertical distance, determine the distance in centimeters that the participant must separate her hands in order to play the video game, and indicate the keystroke needed for the video game selected. Current color selections are those described above: 'Red'; 'Neon Green'; 'Blue'; 'Magenta'; and 'Yellow.' Keystroke selections include those required most commonly by Internet games: 'Space'; 'Left click'; 'x'; 'y'; 'z'; 'Up arrow'; 'Down arrow'; 'Left arrow'; and 'Right arrow.' The current version of the VR_ColorTracker only uses one gesture map to one keystroke during game play. However, the researcher is able to change the gesture and keystroke type depending on the application. In our experience, multiple movements are not possible for most individuals with RTT due to cognitive difficulties.

When the individual separates her hands by a specific distance set by the researcher and the threshold is achieved, the software will send a keystroke signal to the video game to allow game play. A set of freely available Internet video games was established during the development of VR_Color Tracker, and nearly any video game that utilizes a keyboard is compatible; however, we have discovered that some participants with severe cognitive symptoms due to RTT sometimes have difficulty interacting with video games [6]. Therefore, we also designed VR_Color Tracker with the ability to start and stop live videos, often from YouTube, as an engaging alternative with less cognitive load. The keystroke or mouse movement allows the participant to play the video game or listen/watch a video of her choosing. The use of a large computer monitor or TV will allow the participant to see the video game or video

Process

The developed VR_Color Tracker software was used during initial feasibility testing to determine if the distance between the participant's hands could control VR activities. As seen in figure 2, through the use of specific color trackers, markers, or bracelets on the participant's wrists, a webcam allows the person's movements to be detected by the VR_Color Tracker without using a controller or manipulating other input devices. The software then uses the live video from the webcam to monitor and track the distance between the participant's hands in real-time.

This software allows the researchers to determine the distance of hand separation needed in centimeters to lead to a keystroke. The keyboard output selected comes from a predefined list needed to play a specific video game. The ability to translate a specific hand separation distance into a keystroke allows participants to choose from a variety of video games or videos, allowing for more personalized therapy. As the range of motion increases for the participant, the researcher will be able to alter and adjust the distance and plane of movement objectively in order to increase the challenge. Participant's games are chosen based on her motivational and engagement needs as well as on interests and desires.

Participant

To evaluate the initial feasibility of our method of using the color tracker to quantify hand motion, a 51-year-old female diagnosed with RTT was recruited. The participant was non-verbal, communicating with eye gaze, and was wheelchair bound. The upper extremity

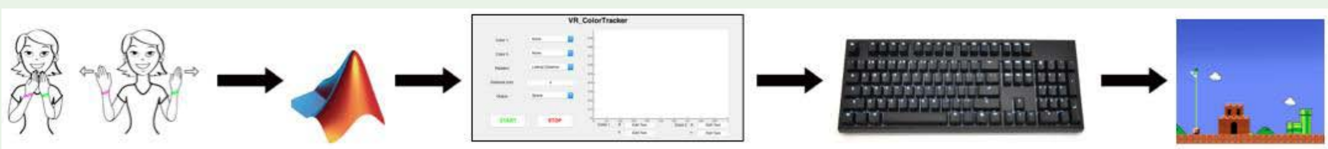

Figure 2: Process for converting hand movement to virtual reality activity.

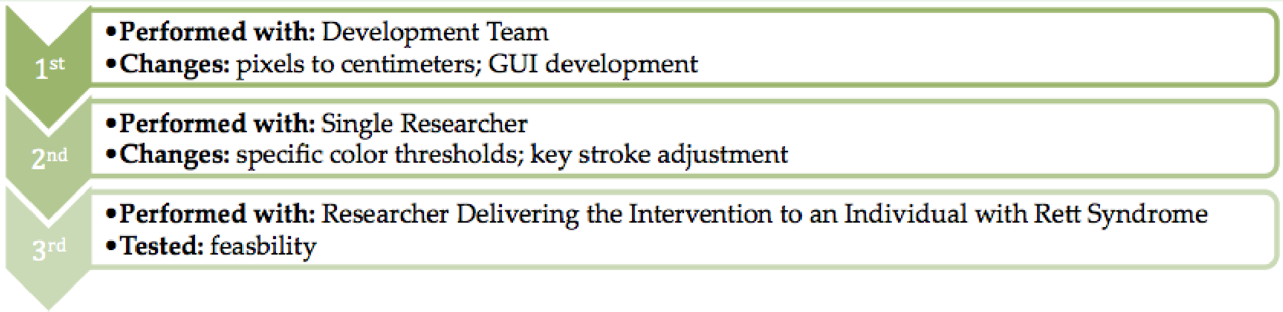

Figure 3: Summary of testing levels.

stereotype displayed by this participant was intense hand wringing. Originally, the participant was unable to engage in an intervention with the Kinect sensor due to the intensity and location of hand wringing against her chest. As a result, we decided to develop the VR_Color Tracker to make it possible for her to participate. The inclusion criteria included: functional range of motion of upper extremities; attention to directions for 60 to 120 minutes; and ability to understand cause and affect. The understanding of cause and affect enables the participant to connect hand movements with a video game or video response. Informed consent was obtained from the individual and the individual's parents prior to feasibility testing. The study was approved by the Georgetown University School of Medicine Institutional Review Board.

Feasibility testing overview

Feasibility testing occurred twice monthly for eight months for approximately one to two hours each visit in the participant's home. During the testing, the participant was placed in front of a large TV, enabling further engagement. Colored markers or bracelets were placed on the participant's wrists in order to detect the participant's hand movements. The researcher then set a desired hand separation movement goal in centimeters required for a video game or video to be played. This threshold was set depending on the participant's range of motion. The participant was then encouraged to participate in video games or to play YouTube videos.

The participant was required to separate her hands by a specific distance in order to cause a specific keystroke, leading to a virtual event in a game or leading to the playing of a video. Each correctly performed distance produced a game-play action or caused the video to play. When the participant's hands returned to midline, the event in a video game halted or the video stopped. Throughout the feasibility testing, verbal cues and encouragement were consistently provided. As the participant progressed, the researchers gradually increased the desired distance of hand separation needed to play the video game. This provided a continuous challenge to maintain engagement and motivation to play, requiring the participant to use both of her upper extremities throughout the testing.

At the end of the feasibility testing, the researcher delivering the video game intervention completed a System Usability Scale (SUS). The purpose of the SUS is to determine the effectiveness, efficiency, and satisfaction of a specific system. The SUS quantifies the ability of users to successfully achieve objectives depending on exertion and gratification. SUS is a ten-item scale with a final score ranging from 0 to 100 [22]. Each item on the item list is scored between 0, strongly disagree, and 5, strongly agree. For items 1, 3, 5, 7, and 9, the adjusted score is the number given minus 1. For items 2, 4, 6, 8, 10, the adjusted score is 5 minus the number given. The adjusted score for each item is then totaled, and the sum is multiplied by 2.5 to give the overall usability percentile [22,23]. The SUS was completed by the researcher since she was using the method to deliver the intervention. Hence, she was best able to comment on the set-up, delivery, implementation, and participant use.

Results

Testing levels

An iterative process of testing, revising, and retesting was performed at three levels (Figure 3). The first testing level was within the investigative team where the process was evaluated for technical issues. The second testing level was with a single researcher where the process was evaluated to ensure that a person with RTT would have success using this system. The third testing level was with a single researcher delivering the intervention to the individual with RTT where the process was evaluated in a clinical setting.

For each level of testing, questions were asked specifically tailored for participants with RTT so that changes could be made. Through direct observation by the intervention researcher, initial introduction of the VR_Color Tracker to the 51-year-old participant with RTT also gave insight to necessary adjustments. Various movement thresholds, body positions (i.e. sitting vs. standing), and lighting were tested for improvements. A summary of these levels of testing is shown in figure 3.

In congruence with developers at Georgetown University, the initial technical usability of the VR_Color Tracker was assessed. Changes made at the first testing level included: (1) changing distance measurements from pixels to centimeters for more feasible measurements by researchers and (2) using a GUI for easy and accurate research use.

After initial changes to the software, the VR_Color Tracker was tested with a researcher familiar with the needs of those with RTT. Changes made at the second testing level included: (1) development of specific color thresholds for more accurate color tracking and (2) incorporating the use of specific keystrokes both when the threshold is reached and when the threshold is not obtained.

After incorporating the changes from both the first and second level of testing, the VR_Color Tracker was retested with a single researcher who delivered the intervention to the participant. At the end of the feasibility testing with the participant, a System Usability Scale (SUS) was completed with the researcher and feasibility was determined.

The outcome of each testing level was to determine the positive and negative aspects of the VR_Color Tracker and to create useful changes. By incorporating these changes, the developed software can be individualized for participants with RTT.

Development team

The first level of testing was done within the development team. It was found that distance measurements made in pixels were not practical for use with researchers since pixels change depending on the distance from the webcam. Researchers would be much more comfortable with the use of inches or centimeters. This would allow researchers to be able to accurately track a participant's progress throughout multiple testing sessions. By incorporating multiple drop-down lists in a GUI, it was found to be a smoother and more efficient experience for the user, ultimately making the session easier for both the participant and the researcher.

Single researcher

The second level of testing was done with a single researcher. It was found that when using primary colors such as red, green, or blue, the VR_Color Tracker had difficulty determining the difference between a colored marker on a wrist and another object of the same color in the room. By incorporating more distinct colors such as neon green, magenta, and yellow, the software was able to pick up only the trackers on the wrists and eliminate others colors in the background. This would also allow the researcher to interact with the participant without the possibility of the researcher being tracked during the session.

It was also found that for specific keystrokes, such as the spacebar, it was useful for the keystroke to be pressed both when the threshold was reached and when the threshold was not reached. For example, if the participant's hands were to be separated by a specified distance, the spacebar would be pressed and a video would be played; however, initially, if the participant's hands were to return to the midline, the video would continue playing since the spacebar would not be pressed for a second time to stop the video. Adjustments made to the software responded to hands returning to midline after the desired movement was achieved, causing the spacebar to be pressed a second time to stop the video. Thus, the participant would be encouraged to separate her hands to continue playing the video and the cycle would continue from there. This would ultimately allow a participant to be more independent during the testing, since prior to the adjustment, the researcher needed to pause the video manually if hands returned to midline.

Pariticipant with rett syndrome

After incorporating the changes from both the first and second level of testing, the third level of testing was engineered with an individual with RTT in order to test the researcher's opinion of its implementation. YouTube videos used during the sessions were chosen based on parent interviews and previous knowledge of the participant's interests. It was found that her interests included Billy Joel songs, Disney movies, and musicals. The participant was required to separate her hands by a set distance in order to play a YouTube video. With this participant, it was found that her right hand remained in place and her left hand movement would lead to the desired distance.

The participant would occasionally reach to rub her face with her left hand as if to scratch it and then keep her hands apart while resting her left hand under her chin. The participant needed assistance throughout the entire session as it took her longer to respond due to her problems with motor planning.

During the personalized testing, the participant was able to activate and deactivate videos as a result of self-initiated movement with few technical difficulties. The participant was continuously engaged in each session, theoretically due to the motivating feedback of hearing the music from the video when the hand separation distance was achieved. The participant would continuously separate her hands to hear the music from the video and was consistently looking at the screen during testing. The researcher also noticed that the participant would also occasionally reach towards the TV screen, which is a long-term goal in therapy for this subject for increasing involvement in activities of daily life. While the VR_Color Tracker is capable of objective measurements such as intervention therapy

Table 1: System Usability Scale (SUS) for the VR_Color Tracker.

Questions	Score	Score after Adjustment
I think that I would like to use this system frequently	4	3
I found the system unnecessarily complex	1	4
I thought the system was easy to use	4	3
I think that I would need the support of a technical person to be able to use this system	3	2
I found the various functions in this system were Well integrated	3	2
I thought there was too much in consistency in this system	4	I
I would imagine that most people would learn to use this system very quickly	4	3
I found the system very cumbersome to use	I	4
I felt very confident using the system	4	3
I needed to learn a lot of things before I could get going with this system	2	3
		Total: 28*2.5=70

duration and distance, those measurements were beyond the scope of this investigation.

The ultimate feasibility percentile was calculated to be in the seventieth percentile. The sixty-eighth percentile is considered above average [23]. Through the use of an adjective rating scale, a SUS score in the seventieth percentile ranks in the "good" category [24]. This score is similar to other investigations in the literature that have established the usability of VR applications in stroke and cerebral palsy [25,26]. The SUS is shown in Table 1.

Discussion

The purpose of this study was to investigate the feasibility of using a color tracker as a method of monitoring the hand and arm motion of individuals with RTT to permit them to play video games as a modality for enhancing motor control. The methods were developed with the ultimate goal of allowing those with RTT to learn and retain skilled hand and arm function while playing video games or watching videos. This feasibility investigation provides support for the use of the VR_Color Tracker as the basis of interventions for those with RTT. As literature has shown, VR-based rehabilitation has proven helpful in those suffering from stoke, brain injuries, and many other diagnoses [7]. Through the use of video games, participants exhibit greater motivation and engagement, ultimately leading to a greater number of repetitions, further improving functional upper extremity use [7-9,16,17]. We are hopeful that our software can be used in a similar manner in the future to decrease the use of stereotypical hand movements specific to individuals with RTT.

The VR_Color Tracker allows individuals to engage in meaningful activities while remaining in a supportive environment. This system allows for a large range of choices and inputs for games or videos, leading to multiple options for therapy. With a large amount of free video games and videos available, finding an activity that interests a participant is very realistic. Ultimately, allowing participants to choose the type of video game may permit for greater motivation and engagement.

Mraz et. al demonstrated that the Kinect could be used for participants with RTT who require less assistance from a caregiver [6]. However, the VR_Color Tracker is usable by those with a greater degree of motor control impairment. The Kinect sensor did not successfully track the most severe RTT participants, so a different strategy was ultimately tested and proved feasible for use with one subject. This software solves the issues that became evident when using the Kinect in that it is capable of (1) tracking the participant in isolation of the researchers or wheelchair, (2) differentiating the researcher from the participant and (3) detecting hands while at midline [6]. Color tracking was applied specifically to an individual with RTT through the use of algorithms including image subtraction, thresholding, and binary masking to identify specific colored markers. Only the color trackers on the participant's hands wearing the markers are viewed by the software and therefore more accurate detection occurred. This prevents the possibility of ineffective sessions as well as allows multiple researchers, family members, or therapists to help the participant at one time.

The use of video games or videos may lead to greater motivation and engagement while performing repetitive, challenging hand movements. In a clinical setting, this could prove very helpful as therapists encourage functional hand use. If successful, we will be able to help people with a greater level of disability as therapists address the repetitive nature of the hand movements found in those with RTT. Thus, this system may prove beneficial as a modality in therapy to improve reaching, which may have direct application to enhancing participation in activities of daily living (ADLs), including play.

As shown with seventieth percentile feasibility according to the SUS, while this is above average, there are some limitations to the VR_ Color Tracker and there are improvements that could be made [22]. Currently, the VR_Color Tracker uses distance in real world units as measured on the display connected to the host computer; however, in the future it may be possible to use depth tracking algorithms to more accurately measure hand separation in three-dimensions within the client's frame of reference. Next steps include the development, recording, and display of clinically relevant performance metrics that can be objectively measured by the VR_Color Tracker. These metrics might include repetitions, range of motion, and movement speed during hand separation movements. In order to improve the power of our feasibility measure in the future, more independent raters, such as clients, caregivers, or therapists not involved in testing, should be included. More feasibility testing should also be conducted with participants who exhibit different types of hand stereotypes as well as different levels of severity in order to assess the capabilities of the developed program.

There is still need for future work with a larger sample size in order to determine the effects that the VR_Color Tracker could have on girls and younger children with RTT. In the future, it may be possible to measure the repetition dose needed to maximize motor performance in hand separation and other therapy activities for individuals with RTT. Also, by expanding the amount of feasibility testing done, the program could be developed and enhanced to address other difficulties that those with RTT have such as balance and ambulation. VR interventions could be used in clinical settings in order to improve motivation and engagement of participants. Since the software allows for easy intervention use, there is a high possibility for this becoming an accessible intervention for individuals with RTT in a home setting [19,21-25]. The long-term effects of this intervention should also be investigated. The use of videogames in a therapy setting and home setting could prove very successful to improve the lives of those diagnosed with RTT.

The VR_Color Tracker was developed and tested specifically for individuals with RTT and created to ultimately lead to a decrease in characteristic stereotypical hand movements and an increase in skilled hand function. At the conclusion of a three-step development process, the software was found to be usable by a researcher delivering an intervention to a person with RTT for the task of separating the hands to engage in virtual media. The person with RTT was successfully engaged in the activity. The results from this study suggest that the VR_Color Tracker may be feasible for use as an individualized approach to RTT therapy. In the future, it is necessary to establish the efficacy of the VR_Color Tracker for increasing functional hand movements, decreasing stereotypical hand movements, improving quality of life, and participating in more daily life activities.

Supplementary Materials

VR_Color Tracker was created using the R2014b version of MATLAB.

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