Virtual reality rehabilitation for all: Vivid GX versus Sony PlayStation II EyeToy

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ABSTRACT

The main objective of this paper was to investigate the potential of the Sony PlayStation II EyeToy (www.EyeToy.com) for use in during the rehabilitation of elderly people with disabilities. This system is a projected, video-capture system which was developed as a gaming environment for children. As compared to other virtual reality systems such as VividGroup's Gesture Xtreme (GX) VR (www.vividgroup.com), the EyeToy is sold commercially at a relatively low cost. This paper presents three pilot studies which were carried out in order to provide essential information of the EyeToy's potential for use in rehabilitation. The first study included the testing of healthy, young adult participants (N=18) and compared their experiences using the EyeToy system to the GX system in terms of sense of presence, sense of enjoyment, control, success and perceived exertion. The second study assessed the usability of the EyeToy with healthy elderly subjects (N=10) and the third study assessed the use of the EyeToy with stroke patients (N=8). The implications of these three studies are discussed.

1. INTRODUCTION

Clinicians who work in rehabilitation aim to enhance clients' functional ability as well as their ability to participate in community life. These goals are achieved by intensive intervention aimed at improving motor, cognitive and meta-cognitive abilities. For many injuries and disabilities the rehabilitation process is very long and arduous, and clinicians face the challenge of finding appealing and motivating intervention tools that will facilitate this process. Virtual Reality-based therapy appears to provide an answer to this challenge due to its well-known assets including the opportunity for experiential, active learning, the ability to objectively measure behaviour in challenging but safe and ecologically-valid environments, while maintaining strict experimental control over stimulus delivery and measurement, and the capacity to individualize treatment needs, while gradually increasing the complexity of tasks and decreasing the support provided by the clinician (Schultheis et al., 2001; Rizzo, 2003).

Although the advantages of VR are becoming widely recognized within the clinical community, the rehabilitation team faces a daunting challenge – to find an off-the-shelf VR system that enables achievement of the goals stated above, yet affordable by the typical clinical facility. A still greater challenge is to find motivating intervention tools that a client could afford to acquire for home-based therapy. This last point is particularly important since, in recent years, it has been demonstrated that only intensive repetition of exercise leads to significant improvement in functional ability (Liepert et al., 2000) yet, due to the high cost of in-patient hospitalization, rehabilitation centres are forced to reduce the time a patient remains in hospital. Thus, therapeutic exercise, initiated and monitored within the occupational therapy or physiotherapy departments, is insufficient on its own, and clients should be provided with opportunities to exercise at home.

For the past few years, a number of clinical research groups have explored the therapeutic potential of VividGroup's Gesture Xtreme (GX) VR (www.vividgroup.com). GX VR is a projected video-capture system; participants stand or sit in a demarcated area viewing a large monitor that displays a environment or functional tasks, such as touching virtual balls. A single camera, vision-based tracking system captures and

converts the user's movements for processing; the user's live, on-screen video image corresponds in real time to his movements, leading to engagement in the simulated task.

This system was originally developed for entertainment purposes, and has been adapted for use in rehabilitation (Kizony et al., 2003; IREX - www.irexonline.com). Different researchers have recently investigated this system (Kizony et al., 2002; Reid, 2002; Sveistrup et al., 2003) demonstrating its suitability for use during the rehabilitation of patients suffering from motor and/or cognitive deficits. Its advantages include the fact that patients see themselves rather than being represented as an avatar. They do not have to wear special apparatus such as an HMD which encourages the use of active movement and reduces their chances of experiencing side-effects. In addition, the therapist can intervene easily during the session in order to support and guide the patient's movements (Kizony et al., 2003).

Despite these many advantages, GX VR is still not widely used in rehabilitation facilities. One of the major reasons for this limited usage is the cost of the system that keeps it out of the price range of many clinical settings. The PlayStation II EyeToy (www.EyeToy.com), recently released by Sony, Inc, is an off-the-shelf, low-cost gaming application, which provides the opportunity to interact with virtual objects that can be displayed on a standard TV monitor. As with the Gesture Xtreme system, the EyeToy displays real-time images of the user. However, it does not require a chroma key blue/green backdrop behind the user nor bright ambient lighting. This makes for an easier setup of the system in any location but, on the other hand, it means that the user sees himself manipulating virtual objects within a video image of his own physical surrounding rather than within different virtual environments. The EyeToy application includes many motivating and competitive environments which could be played by one or more players (e.g., boxing, spinning plates) as well as different visual effects which encourage active movement without giving a score (e.g., painting a rainbow, mirror image distortions and popping bubbles).

The EyeToy's low cost and easy setup are advantages that have encouraged us to consider its use in rehabilitation, and to investigate its usability for wide segments of the population and not just for children who were the original market targeted by this application. It is also essential to verify that the levels of exertion evoked by this application are within the physiological capacity of patient populations, many of whom are elderly or weak.

2. OBJECTIVES

The main goal of this study was to assess the potential of the EyeToy for use in rehabilitation with people who are elderly and have disabilities, such as those who have had a stroke. This was achieved by performing three different pilot studies:

Study 1: To compare the GX and EyeToy applications using healthy young participants in terms of their effect on users' sense of presence, level of enjoyment, perceived exertion and side effects.

Study 2: To assess the usability of the EyeToy with an elderly healthy population in terms of sense of presence, level of enjoyment, perceived exertion and side effects and their ability to operate the system.

Study 3: To assess the use of the EyeToy with patients who have had a stroke in terms of their ability to cooperate, use different applications, and their level of enjoyment and perceived exertion.

3. STUDY 1

3.1 Participants

Eighteen healthy participants aged 21-37 (mean age 25.3 ± 4.0 years), mostly university students, volunteered to participate in the study. To date, 17 subjects were females and one was male. This ongoing study will eventually include more male participants.

3.2 Instruments

3.2.1 Virtual Reality Systems and Environments. VividGroup GX System was used with two virtual environments; Birds & Balls - touching balls that approach the user in a pastoral setting (Fig. 1a) and Soccer - preventing balls from entering the goal crease (Fig 1b). The Sony PlayStation EyeToy was used with two virtual environments too; Wishy-Washy - cleaning windows (Fig 1c) and Kung-Foo - fighting off other Kung-Foo fighters who are attacking (Fig 1d).

3.2.2 Presence Questionnaire (PQ). The PQ was translated from Witmer & Singer (1998) and used to assess presence. It is composed of 19 questions in which participants use a 7-point scale to rate various experiences

within the VE; the maximum total score is 133 points indicating a high level of presence. The items assessed different aspects of presence: involvement/control, natural, interface quality and resolution. This was administered after each system.

Based on Slater's (2003) recent comments about the construct of presence, an additional question was asked: "During the time of the experience, which was strongest on the whole, your sense of being in the virtual environment, or of being in the real world of the laboratory?" This question was rated on a scale from 1 (being in the real world of the laboratory) to 7 (being in the virtual environment). This question was asked after participants experienced each system.

3.2.3 Scenario Feedback Questionnaire (SFQ). The SFQ is based, in part, on a translated version of Witmer and Singer's (1998) Presence Questionnaire) and was administered after each environment (virtual game). These six items assessed the participant's (1) feeling of enjoyment, (2) sense of being in the environment, (3) success, (4) control, (5) perception of the environment as being realistic and (6) whether the feedback from the computer was understandable. Responses to all questions were rated on a scale of 1-5, which were combined to give a global response to the experience for a maximum score of 30. An additional question was added to inquire if the participants felt any discomfort during the experience.

3.2.4 Borg's Scale of Perceived Exertion (Borg, 1990). This scale was used to assess how much physical effort the participants perceived that they expended during each VR experience. This is a 20-point scale that participants rated from 6 (no exertion at all) to 20 (maximal exertion).

3.2.5 Performance. Performance was monitored using the scores obtained in each environment (environment). For the Wishy-Washy environment the number of windows in addition to the total number of pints was recorded and for the Kung-Foo, the number of enemies and total number of points was documentation.

3.3 Procedure

Each participant experienced two virtual environments for three minutes on each of the VR systems: For the GX, Birds & Balls and Soccer and for the EyeToy, Wishy-Washy and Kung Foo were used. For all four environments the users were required to move their arms and bodies in order to interact. After experiencing each virtual environment, the participants were asked to complete the Scenario Feedback Questionnaire (SFQ). After experiencing the two environments using the first VR system, Witmer and Singer's10 Presence Questionnaire was completed. Participants then underwent the same procedure with the second VR system. The order of VR systems was balanced across participants. The entire experimental procedure took place during a single session lasting about 40 minutes. At the end of the procedure the participants were asked to rate the four environments in terms of enjoyment.

3.4 Data Analysis

Paired t-tests were used in order to determine differences between the sense of presence for each of the two systems (as assessed by the PQ and Slater's (2003) Presence question). Repeated measures were used to assess the differences between the four virtual environments (for the total SFQ, for the first question of the SFQ (sense of enjoyment) and for perceived exertion). This was followed by paired t-tests in order to identify the source of the significance.

3.5 Results

As a first step for each analysis we examined whether the order of experiencing the VR systems influenced the results. There were no significant differences due to the order in which the VR systems were experienced by participants for any of the outcome measures.

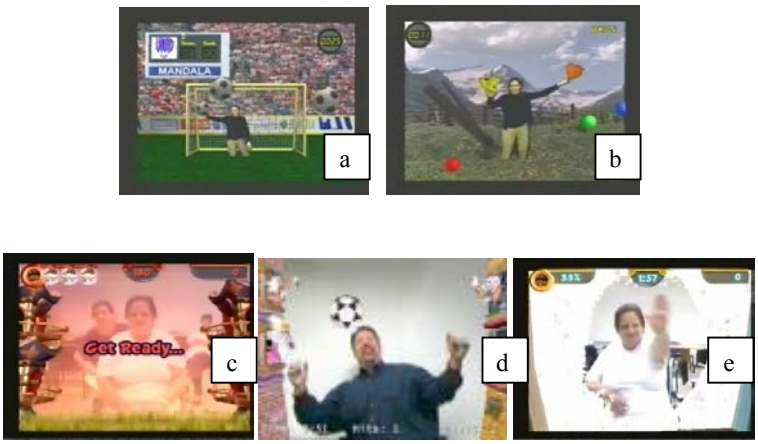

Figure 1. *Screen shots of the virtual environments. The two GX environments included (a) Birds & Balls and (b) Soccer. The three EyeToy environments included (c) Wishy-Washy, (d) Kung-Foo and (e) Keep-Ups.*

3.5.1 Differences between systems. The mean total PQ score for the GX environments was 94.1 ± 9.3 points (out of a maximum 133 points) and for the EyeToy environments was 93.7 ± 8.4. These mean scores were not found to be significantly different. The mean score for Slater's presence question for the GX system was 3.6 ± 1.2 points (maximum 7 points which indicates full presence in the virtual environment); this was not significantly different than the mean of 4.1 ± 1.6 points for the EyeToy system.

3.5.2 Differences between the four environments experienced by each participant. Significant differences between the environments were found for the total SFQ ($F(15)=5.970$, $p<.007$). The score for Kung-Foo was 25.3 ± 3.4 points which was significantly higher than the scores for Soccer (21 ± 3.6 points) ($t(17)=-3.88$, $p<.01$) and for Birds & Balls (21.8 ± 3.2 points) ($t(17)=-3.96$, $p<.001$) (see Table 1).

Significant differences were also found for the sense of enjoyment (the first question of the SFQ) ($F(15)=12.06$, $p<.00$). When paired t-tests between the different environments were used, significant differences were found between Kung-Foo and Birds & Balls ($t(17)=-5.02$, $p<.000$), between Kung-Foo and Soccer ($t(17)=-4.507$, $p<.000$) and between Kung-Foo and Wishy-Washy ($t(17)=-3.716$, $p<.002$) all in favour of Kung-Foo.

The differences in perceived exertion between each of the four environments were found to be significant ($F(15)=12.068$, $p<.000$), where Birds & Balls was considered to be significantly easier than Soccer ($t(17)=-6.460$, $p<.000$), Wishy-Washy ($t(17)=-3.401$, $p<.003$) and Kung-Foo ($t(17)=-3.987$, $p<.001$) (see Table 1).

4. STUDY 2

4.1 Participants

Ten healthy elderly participants (six women and four men) aged 59-80 (mean age 70 ± 5.7) years were included.

4.2 Instruments

4.2.1 Virtual Reality Systems and Environments. Sony PlayStation EyeToy was used with three virtual environments; Wishy-Washy - cleaning windows, Keep-ups - bouncing a virtual soccer ball (See Fig. 1e) and Kung-Foo - fighting off other Kung-Foo fighters who are attacking

4.2.2 Scenario Feedback Questionnaire (SFQ). This scale ranges from 6-30 points (See above for further details)

4.2.3 Borg's Scale of Perceived Exertion [9] (See above for further details)

4.2.4 Usability Questionnaire. This questionnaire is composed of ten questions; five positive and five negative items regarding the use of the system. Each system was rated from 1 (disagree totally) to 5 (agree totally). The absolute sum of the 10 questions was calculated for a total score which ranged from 10 to 50 points.

Table 1: *Results from the total SFQ, sense of enjoyment and Borg scale for the four virtual games.*

	GX System		EyeToy system	
	Soccer	**Birds & Balls**	**Kung-Foo**	**Wishy-Washy**
Total SFQ	21 ± 3.6	21.8 ± 3.2	25.3 ± 3.4	23.5 ± 4.4
Sense of enjoyment	3.6 ± 0.92	3.6 ± 0.85	4.7 ± 0.43	4.2 ± 0.92
Borg scale (6-20)	13.6 ± 2.4	10.6 ± 1.8	13.4 ± 2.8	12.9 ± 2.6

4.3 Procedure

The participants experienced the EyeToy in their homes. Prior to the two minute experience with each environment, they were given a minute to practice. After each environment they were asked to fill in the SFQ and rate their perceived exertion. Their performance within each environment was recorded. Upon completion of the three environments, the participants were requested to independently exit the Kung-Foo environment and to start the Keep-Ups environment. The sequence of their actions was monitored. They were then asked to fill in a usability questionnaire regarding the use of the EyeToy.

4.4 Data Analysis

To assess differences between the three virtual environments (for the total SFQ, the first question of the SFQ – sense of enjoyment) and perceived exertion repeated measures were used, followed by paired t-tests. Independent t-tests were then used to compare the results of the ten elderly participants to the 18 younger participants in terms of their SFQ, perceived exertion and performance in two of the environments (Wishy-Washy and Kung-Foo).

4.5 Results

Significant differences were found between the environments for the participants' sense of being in the environment, of enjoyment, control and success as reflected from the total SFQ score ($F(8.0)=7.724$, $p<.014$). The SFQ score for the Wishy-Washy environment was the highest (25.3 ± 3) and it was found to be significantly higher ($t(9)=-3.245$, $p<.01$) than Keep-Ups (18 ± 5.7). The SFQ score for Kung-Foo (23.2 ± 4.5) was also significantly higher than Keep-Ups ($t(9)=4.134$, $p<.003$).

Regarding the sense of enjoyment (the first question of the SFQ), significant differences were found between the three virtual environments ($F(8)=5.024$, $p<.04$); paired t-test revealed that the significant differences were between Keep-Ups (3.5 ± 1.0 points) and Kung-Foo (4.5 ± 0.7 points) ($t(9)=-3.354$, $p<.008$); Wishy-Washy (4.3 ± 0.9 points) did not differ significantly from the other environments. The perceived exertion for all three environments was very similar, 11.0 ± 2.6 for Kung-Foo, 11.3 ± 1.4 for Wishy-Washy and 11.3 ± 1.4 for Keep Ups. No significant differences were found. A mean usability score of 43.3 ± 4.0 points (maximum possible score = 50) was found as a result of the participants operating the system on their own.

The overall experience using the EyeToy system by the younger (N=18) and older (N=10) participants was compared. No significant differences between the groups were found for either Wishy-Washy or Kung-Foo (see Tables 2 and 3 for further details). During the Wishy-Washy environment, participants from both groups succeeded in cleaning a mean of 5 windows during the 180 s environment. The younger group reported feeling more fatigue upon completion of the environment than did the older group but this difference was not significant.

During the Kung-Foo game, no significant differences for the total SFQ were found between the groups, however, significant differences were found for the Borg scale, and the number of enemies killed during the first game. The Kung-Foo game is not limited by time but you have two lives before "game over". In order to reach a full two minutes of engagement in the game, some participants had to continue playing into a second game. Most of the young participants managed to complete one full game, taking two minutes to do so. In contrast, the older participants needed 1.9 ± 1.1 games on average (range 1 to 4 games) to complete the two minute experience. This difference was significant ($t = -2.586$, $p<.03$).

Table 2: *Differences between age groups for the Wishy-Washy environment*

	Age group 59-80 N= 10	Age group 21-37 N=18	t	p
SFQ (6-30)	25.3 ± 3	23.5 ± 4.4		NS
Borg scale (6-20)	11.3 ± 1.4	13 ± 2.6		NS
# window's cleaned	5.5 ± 2.3	5.6 ± 2		NS
Total points	15,124 ± 7,523	15,888 ± 8,117		NS

Table 3: *Differences between age groups for the Kung-Foo environment*

	Age group 59-80 N= 10	Age group 21-37 N=18	t	p
SFQ (6-30)	23.2 ± 4.5	25.3 ± 3.4		NS
Borg scale (6-20)	11 ± 2.6	13.4 ± 2.8	2.147	.041
# of enemies killed	46 ± 40	86 ± 52	2.108	.045
Total points	13,780 ± 12,997	23,033 ± 16,137		NS

5. STUDY 3

Due to the positive response of the healthy elderly participants in Study 2, it was considered appropriate to test the EyeToy with participants with stroke.

5.1 Participants

Seven patients with stroke participated in this study. Two of the participants lived at home and had a mean post-stroke interval of 2.5 years. Five patients had a stroke within the past 2.5 months and were still in the process of receiving acute rehabilitation. All seven patients had sustained a right hemispheric stroke causing left hemiparesis. Table 4 presents additional data on each of the seven patients.

5.2 Instruments

The Sony PlayStation EyeToy was used with Wishy-Washy (cleaning windows) and Kung-Foo (fighting off other Kung-Foo fighters who are attacking). The Scenario Feedback Questionnaire (SFQ) rated from 6-30 points and Borg's Scale of Perceived Exertion were also used (see above for further details).

5.3 *Procedure*

The two chronic patients experienced the two virtual environments at their home while the five patients in acute rehabilitation experienced the environments at the hospital. They were given a practice minute prior each of the environments, followed by 2 minute experience using first Wishy-Washy and then Kung-Foo. After each environment they were asked to fill in the SFQ and rate their perceived exertion.

5.4 Data Analysis

Due to the small sample size of this initial study with stroke patients, descriptive statistics were used when available. In some cases, it was only possible to report on our observations of performance and reaction to the EyeToy.

5.5 Results

5.5.1 Chronic stroke patients. The two chronic stroke patients reported great enjoyment during their experiences with the EyeToy games. During the Wishy-Washy game they both requested to hold a towel in their hand, a prop that appeared to help them perform the task of cleaning windows. They all enjoyed the game very much (5/5). The total SFQ for both participants was 27/30 points. They rated exertion at 13-15 points and reported fatigue of their weak upper extremity. They were encouraged to use their weaker left arm as well as their strong arm and they did succeed in use it for cleaning the left side of the window. The number of windows cleaned was 1 or 2 with 1100-2988 points. This is much less than the scores of the healthy elderly although we cannot do statistics due to the small sample size.

Both participants enjoyed Kung-Foo very much (5/5 points) with a total SFQ of 27-28 points; they preferred using it more than Wishy-Washy. The level of exertion was rated in the same manner as for Wishy-Washy (13 to 15 points). Their Kung-Foo character was eliminated very quickly causing the game to end; this took 18 to 30 sec for the first game, 12 to 45 sec for the second game and 36 to 48 for the third game. These fast eliminations did not appear to frustrate them since they understood its therapeutic value (especially its value as good exercise for their weak upper extremity). Moreover, they were aware of and encouraged by the fact that their scores improved with each successive game; managed; they gained 400 to 2,100 points for the first game, 1,600 to 6,400 for the second and 3,400 to 6,300 for the third.

5.5.2 Acute stroke patients. All five patients enjoyed their experience very much and said they would happily repeat it. Several of the participants had difficulty using the SFQ to rate their answers. Participants 4 and 5 became frustrated during the games since they could not use their weak upper extremity to interact with the virtual objects. They understood the therapeutic value for their upper extremity and therefore were not satisfied when they accomplished the task using their right unaffected arm. We noted that all patients had

difficulty in interacting in the space beyond their own bodies. Rather, they primarily moved their hands in front of their body. This was a limitation, especially for the Wishy-Washy game since the current window must be completely cleaned before the next one appeared. Many of the patients would have been stick cleaning the same window without help from the therapist. Participant 2 was relatively young and had considerable active movement in her left weak arm. Out of the five acute patients, she was the one who gained the most from the experience with the EyeToy.

Table 4: *Characteristics of the patients with stroke*

	Age	*Sex*	*Months post stroke*	*Functional status – independence*	*MMSE*	*Mobility*	*FMA- Left upper extremity*
1	*91*	*F*	*2*	*dependant*	*24/27*	*wheelchair bound*	*37/60*
2	*59*	*F*	*1*	*BADL - partial*	*20/28*	*wheelchair bound*	*45/60*
3	*72*	*F*	*2*	*dependant*	*NA- Aphasia*	*wheelchair bound*	*52/60*
4	*73*	*F*	*3*	*dependant*	*27/30*	*wheelchair bound*	*11/60*
5	*70*	*M*	*2*	*dependant*	*28/30*	*wheelchair bound*	*18/60*
6	*74*	*M*	*30*	*BADL & IADL*	*30/30*	*walk independently*	*48/60*
7	*69*	*M*	*36*	*BADL & IADL*	*30/30*	*walk independently*	*32/60*

F-female, M- male
FMA – The Fugl-Meyer Motor Assessment assesses the ability to perform different movements with the weak upper extremity. The scores ranges from 0 (no active movement) to 60 (full active movement).
BADL- Basic activity of daily living (such as eating, dressing, bathing).
IADL- Instrumental activities of daily living (such as cooking, shopping, house chores).
MMSE – Mini Mental Status Examination- cognitive screening test (maximum 30 points).
NA- Not applicable due to Aphasia (language disorder).

6. SUMMARY, CONCLUSIONS & RECOMMENDATIONS

The main goal of this study was to assess the potential of the EyeToy for use in rehabilitation with people who are elderly and have disabilities. Three pilot studies were carried out in order investigate the EyeToy's potential. The first comparison study demonstrated that the young participants sensed the same level of presence while experiencing the EyeToy as they had while experiencing the expensive GX system. Overall the participants enjoyed the four environments, but had a clear preference for Kung-Foo. The exertion levels were the highest for Soccer and the lowest for Birds and Balls. The importance of second pilot study was the fact that the elderly healthy participants enjoyed using the EyeToy, especially during the Wishy-Washy followed by Kung-Foo and then the Keep-Ups game. A high score for the usability questionnaire was obtained, indicating their satisfaction with the system and its ease of use. The EyeToy system, and especially the Kung-Foo, was found to be sensitive and differentiate between young and older participants and between stroke patients.

Assessing the use of the EyeToy with stroke patients emphasized the EyeToy's limitation, in particular the inability to grade the level of the environments. The EyeToy seemed to be less suitable for the acute stroke patients since they suffered from severe weakness of their left side of their body accompanied by sensory, cognitive and language deficits in some cases. Due to this fact, some of the patients expressed frustration especially when they could not manage to interact with the images with their weaker hand. Due to this limitation, the therapist is often required to help patients, for example, by bringing them closer to the camera (to make them appear larger) or by seating them on one side instead of the middle in order to facilitate performance. In some cases it is necessary to provide the patient with physical guidance or help. Despite this fact all of the acute stroke patients enjoyed their experience and expressed interest in repeating the session. However, the games appear to have the most potential for chronic patients or patients who sustained a mild stroke. Another limitation of the EyeToy is that the data recording is not sufficient .

The assets of the EyeToy, which were demonstrated by the results of all three studies, are that it is low cost, easy for users to operate, interesting, motivating and enjoyable. There is no doubt that these are all very valuable as an intervention tool during the rehabilitation of stroke patients and those with other neurological disorders. Motivated patients would be encouraged to practice movements in a repetitive manner using the EyeToy, thereby improving their condition. This is not easy to achieve via conventional therapy (Liepert et al., 2000). Moreover, the EyeToy appears to be ideal for use by the patient at home, where their healthy elderly caregiver would be able to operate the EyeToy for them. This is very important since the rehabilitation process after stroke is very long and, indeed, never ends. Patients living at home can benefit

from using the EyeToy which requires the use of active movement of the whole body, attention, and rapid responses.

It is nevertheless unfortunate that despite the promise of using the EyeToy with a patient population, these environments cannot be graded to suit low functioning patients or in order to train specific therapeutic goals. During the past several years, other, similar products came on the market (e.g., by Intel and Reality Fusion) but were discontinued. Given the need for a low-cost VR video-capture tool that can be graded it is hoped that new products will soon become available.

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