Virtual Reality System for Rehabilitation of Children with Cerebral Palsy: A Preliminary Study

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Abstract: We present a non-immersive virtual reality (VR) system for the rehabilitation of children with Cerebral Palsy (CP). Our objective is to encourage and motivate children to improve their limb motor control while playing a game. Two tasks are available: (1) intercepting or (2) catching / releasing moving objects using a Kinect^{TM} sensor. These tasks are achieved via the control of a virtual character placed in a virtual island. A control-display ratio is used to virtually increase the child workspace allowing him/her to intercept moving objects from any direction. In addition, a dynamic difficulty adjustment (DDA) is used to keep a good motivation level. Furthermore, virtual coach is provided to support and congratulate the children. Twenty healthy children participated in a preliminary experiment. The aim was (1) to collect control data concerning performance and workload, and (2) to investigate the effect of the virtual coach. Results show a good usability of the game and reveal a high ratio of acceptance and enjoyment from the children.

1 INTRODUCTION

Cerebral palsy (CP) is a term that refers to various motor impairments caused by damage to the central nervous system during foetal development. Traditional CP therapies are often of little interest to a child, affecting his motivation to continue therapeutic activities (Schmidt and Lee, 2005). For example, Constraint-induced movement therapy (CIMT), often used to improve upper limb function encourages the use of the affected hand by restricting the unaffected hand and asking for intensive movement with the impaired upper limb (Hoare et al., 2007). Having the good arm blocked for long periods of time can generate frustration and might not be applicable in a long-term rehabilitation program.

More child-friendly approaches are needed during the neuro-development of children with CP. For example, rehabilitation programs should offer therapeutic games that are specifically designed to encourage the child to use their affected limb and even both arms in coordination. The proposed games should be easy to use and non-intrusive in order to affect children movements.

The paper is organized as follows: the next section provides a survey of the related work concerning interactive motor rehabilitation systems and adaptive games. Section 3 presents an overview of our system and its innovative characteristics. In Section 4, we describe our approach for the auto-adaptation of the system. Section 5 is dedicated to the experimental study. Section 6 concludes the paper and discuss directions for future work.

2 RELATED WORKS

2.1 Rehabilitation Systems

Virtual reality (VR) or Virtual Environments (VEs) may be described as multi-sensory, interactive and immersive computer-based 3D environments that could be used to simulate some aspects of the real world. VR is now recognized as a powerful tool for the assessment and rehabilitation of both motor and cognitive impairments and provides a unique medium for the achievement of several requirements of effective rehabilitation: controlled conditions, repetitive practice and feedback about performance (Riva,

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2003; Burdea, 2003; Gaggioli et al., 2009; Halton, 2008; Raspelli et al., 2012; Cipresso et al., 2012; Pallavicini et al., 2013). In addition, VR offers boundless variations of augmented feedback, objects, and allow the users immersion in attractive environments (Cikajlo et al., 2010; Berger-Vachon, 2006) so that VR remains motivating and entertaining (Rand et al., 2009).

Few virtual rehabilitation systems have been developed for motor rehabilitation using full-body interaction. For example, Kizony et al., (Kizony et al., 2003) proposed IREX, based on a video-capture system. A single camera is used for vision-based tracking to capture the users movements. The captured video images can be displayed on a connected TV screen, corresponding in real time to his movements. Its suitability has been investigated for use during motor or cognitive rehabilitation (Rand et al., 2004). The Cybex Trazer^{TM} employs a single infra-red beacon which is mounted on a belt worn around the waist of the user. The user's motion is captured by monitoring the sensor's position by the tracker bar (Fitzgerald et al., 2007). The EyeToy^{TM} game uses a single camera to capture the users movements. Interaction with an on-screen user avatar can only track movements in a single plane and is not able to record body movements (Fitzgerald et al., 2007). For a review, a review see Adamovich et al., (Adamovich et al., 2009).

Some research used others interaction techniques to rise the motivation of children with CP in their motor rehabilitation exercises. For example using VR devices with Wii^{TM} or with Kinect^{TM} , the children showed improvement in the motor rehabilitation with VR devices (Sharan et al., 2012; Deutsch et al., 2008; Ortiz-Gutirrez et al., 2013; Chang et al., 2013). Indeed Chang, Han and Tsai (2013) asked two teenagers to move their arms in front of a screen. When they made correct movement a song was broadcast and a cartoon character was displayed. In our study, to support children's motivation, we propose to use a virtual coach and found the rehabilitation process on a playful approach.

2.2 Adaptive Games

Dynamic Difficulty Adaptation (DDA), also known as Dynamic Game Balancing (DGB), is the process of automatically changing parameters, scenarios, and behaviours in a video game in real-time, based on the player's ability, in order to avoid them becoming bored (if the game is too easy) or frustrated (if it is too hard) (Huang et al., 2010). In recent years, studies have used different approaches to handle DDA. For example, Parnandi et al., (Parnandi et al., 2013) proposed an approach based on control theory's principles. They used variation of actual and desired arousal of the user as the variation error to minimize. They conducted an experiment on 20 subjects through a Car-racing application. Hocine and Gouaïch (Hocine and Gouaïch, 2011), described an approach based on prior assessments of the capability of the user. The adaptation is done through an ability zone, which contains information on the difficulty to do a given task at given position. They conducted an experiment on 8 subjects through a reaching-task application.

Gouaïch et al., (Gouaïch et al., 2012) proposed a digital pheromone approach based on the ant algorithm introduced by (Dorigo and Stützle, 2004). The adaptation is done through an ability zone updated regarding users performance. They conducted an experiment on 10 subjects through a reaching-task application. Arulraj et al., (Arulraj, 2010) proposed a differential learning approach for NPC. The agent learning-rate reduces with time, while being impacted by users performance. The approach feasibility has been tested using the Minigate game. Andrade (Andrade and Ramalho, 2005) and Tan (Tan et al., 2011) both proposed a Reinforcement Learning (RL) approach for NPC. Andrade implemented it by using the Q-learning algorithm, the adaptation being done by choosing the action-value which fit the level of the user. The approach feasibility has been tested using a fighting application. Tan implemented it by using Adaptive Uni-Chromosome Controller (AUC) and Adaptive Duo-Chromosome Controller (ADC) algorithms, the adaptation is being done by activating controller's behaviour which fit the level of the user.

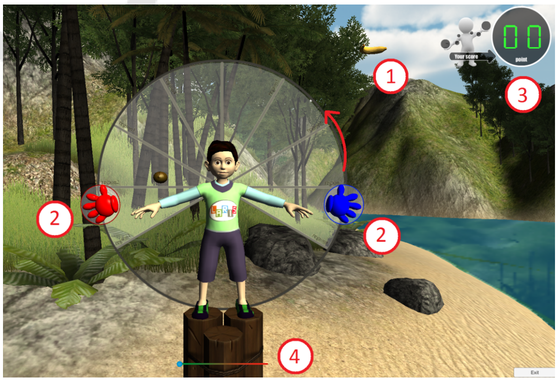
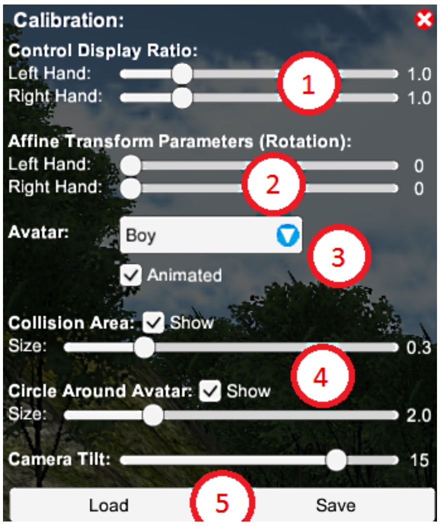


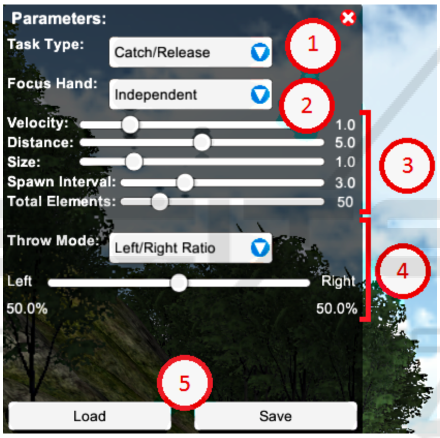
Figure 1: Screen shot of the rehabilitation game.

3 SYSTEM DESCRIPTION

The goal of our research is to develop an innovative interactive virtual rehabilitation system which enables children with CP to play while improving their motor



(a)



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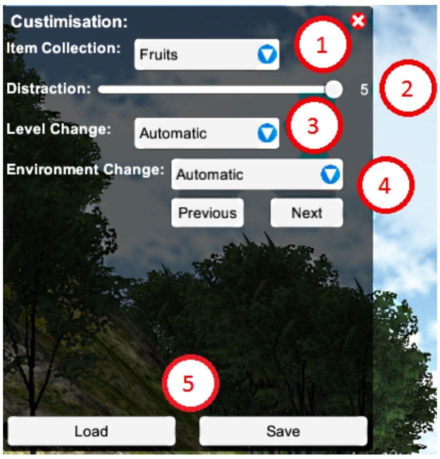


(c)

Figure 2: Interaction techniques : (a) using the game-pad only, (b) using the game-pad and the TrackIR^{TM}, (c) and (d) using the kinect^{TM} and the TrackIR^{TM}.

control of the limb. This requires the use of a non-intrusive motion capture device such as the Microsoft Kinect^{TM} and the possibility to increase the children workspace allowing him/her to reach and intercept any moving objects. The proposed approach enables a modifiable control-display ratio together with dynamic difficulty adjustment (DDA) capabilities used to keep children motivation.

The game takes place in a virtual island. Figure 1 shows a screenshot of the rehabilitation game. The avatar is controlled (arms only) in real-time by the child facing the visual display. The goal is to animate the avatar in order to intercept, or catch and release the virtual objects. A Kinect^{TM} sensor is used to get the 3D motion data from the child's arms.

The user may intercept or catch and release the virtual objects ① using virtual hands ②. While the virtual character' arms are moving is 3D space, both the virtual hands and the approaching objects are constrained in a vertical plane. Thus, the subject does not have to manage the depth. In addition, as previously mentioned, to allow the children with motor disability to perform the task, a control-display ratio has been implemented (amplification of movements). An important aspect is that a control/display ratio (less than 1/1) could be used to encourage the children with CP not to use his/her "good" hand, but rather his/her paretic hand.

In order to keep the children motivation to play the game and keep exercising, we constantly display the score ③ on the upper right corner of the screen. At the bottom of the screen, a scroll bar is displayed to inform the children about the current difficulty level of the game.

The system proposes different menus to set-up the game parameters. The first menu, illustrated in Figure 2 (a), allows to set the value of the control/display ratio for both the right and the left hands ①. We could also set-up the affine transform parameters ②. Then, we could select different avatars (boy, girl, animated or not). We can display a circle around the avatar to illustrate the hands movement constraint and also set and display the collision area (on both hands) used for intercepting the objects ④. Finally, we can save the parameters and load any set-up ⑤.

The second menu, illustrated in Figure 2 (b), is mainly used to select the task ① : intercept or catch and release, and select with which hand ② the child have to use to perform the task (right hand, left hand, any of them, or with both hands joined). We can also set the task's parameters ③ such the size, velocity, or frequency of occurrence (spawn interval) of the objects (Figure 5).

The third menu, illustrated in Figure 2 (c), is used to select the set of objects that will have to be caught ①. Is this menu, we can also choose a level of distraction ②, ranging from a static white background to a fully dynamic virtual island including moving objects and sounds. This menu also allows to set the way (manually or automatically) the difficulty level ③ will be changed and the way the task will be displaced in the island after each session ④. In addition the system allows to set the area from which the moving objects will approach the avatar. For example, in the Figure 3, the main direction (red line) can be tuned to a given angle. In addition, a range (width) around this main direction can be tuned manually on the circle around the avatar.

Figure 3: Setting the area for the approaching objects.

3.1 Control/Display Ratio

The Control/Display (C/D) ratio is the ratio between the amplitude of movement of the user's real arm and the amplitude of movements of the virtual cursor (Dominjon et al., 2005). The C/D ratio may be used to increase the user's physical workspace allowing him/her to move in a larger workspace. Since patients with impaired motor functions have a limited (hopefully increasing) ranges of movement, a C/D ratio may help them to perform task as the people without any impairment.

3.2 Dynamic Difficulty Adaptation

In order to maintain the child's attention and motivation to an acceptable level, we implemented a Dynamic Difficulty Adaptation (DDA) protocol. We proposed that the game difficulty is dependant of (1) the task parameters, (2) the game ambiance, and (3) the interaction technique used to perform the task. In the context, we propose to use a virtual coach (Figure 6) to support, congratulate or advise the child after each game session.

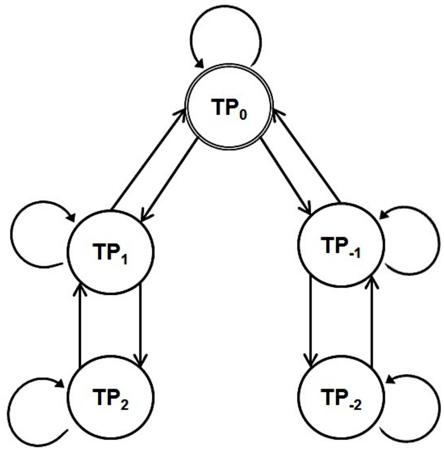


Figure 4: Task-Difficulty-Automaton.

Figure 4 shows the automaton related to the evolution of the task's difficulty. In this automaton, TP_0 is the initial state vector of the parameters. This parameters are tuned according to the user's personal profile. If the user performance (score), is less that 30% or more that 80% of catches, then the TP_0 state switches to the TP_{-1} (difficulty is decreased) or TP_1 (difficulty increase) states respectivelly. The task difficulty could then be further decreased (TP_{-2}) or increased TP_2 or returns to the initial state (TP_0) according to the same given thresholds. This approach will keep the child motivated, because if the game is too easy or too difficult he/she will not keep playing.

3.2.1 Interaction Technique

The interaction technique parameters could also impact the task difficulty. These parameters are: (1) the control/display ratio (ratio between the child movements and avatar movements), (2) the feedbacks (sounds from collision with the moving objects or haptic feedback), (3) movement constraints (in our case 2D projection of 3D movements), and (4) time delay between the child movements and the avatar movements.

3.2.2 Virtual Coach

The behaviour of the virtual coach is the following. At the beginning of the game, the coach tell the story, explain the goal of the game and the task. Then he disappears from the screen. At the end of each session, the virtual coach appears to (1) congratulate the child in case of a good score (more than 80% of catch), (2) advise the child in case of a bad score (less than 30%

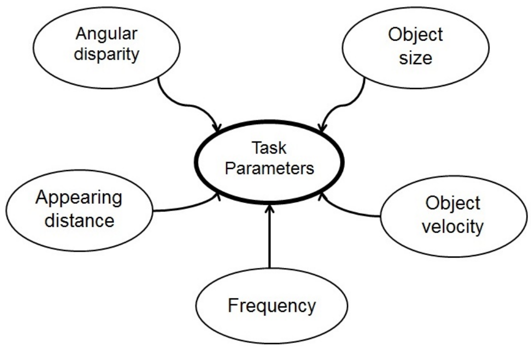


Figure 5: Diagram for task parameters.

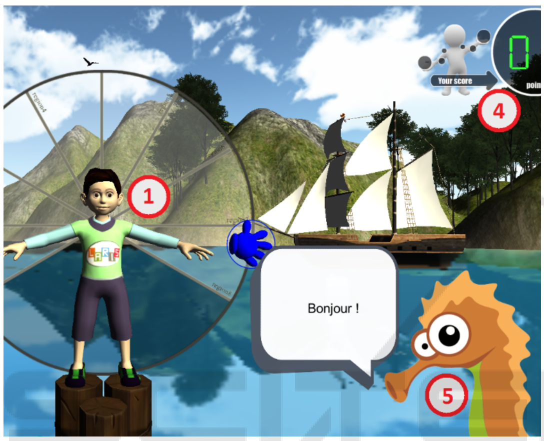


Figure 6: Illustration if the virtual coach.

of catch), or (3) to support the child if the score is between these two thresholds.

4 USER STUDY

4.1 Aim of the Study

The aim of this study is twofold. Firstly, we want to collect control data with healthy children in order to have a baseline for comparison with CP children. These data are related to performance (score) but also to the usability of the system, the enjoyment, the task and the game-play. Secondly, we would like to investigate the effect of the virtual coach on both performance data and subjective data.

4.2 Method

4.2.1 Design and Procedure

Twenty children from a primary school in Angers (France) participated in the study. The task consisted

Figure 7: Experimental set-up.

in catching a total of 200 objects (fruits: pineapple, banana, kiwi and apple) during four sessions (50 objects in each session). The children were split in two groups of 10 children each. The first group performed the task in condition C_1 (without the virtual coach), while the second group performed the task in condition C_2 (with the virtual coach). Children were allowed to get a rest of 5 minutes between sessions.

The fruits were launched randomly from starting point above the avatar's shoulders (direction was set to 0 degree and width was set to 90 degrees). The control/ratio display was set to 1/1. The task difficulty was kept constant throughout the experiment. Thus, the objects always moved at a constant velocity of 0.2 $m.s^{-1}$. The children have to use their dominant hand. The task took place in a different position for each session. Concerning the sounds, a tropical forest ambiance was displayed including birds, monkey, etc.

The assertions submitted to the children in the main questionnaire were the following:

1. I had a lot of fun playing the game,
2. I found the game interesting,
3. I found the game boring,
4. The game caught my attention,
5. I found this game somehow complicated,
6. I liked the graphics of the game,
7. I liked the sounds of the game,
8. I liked the game scenario,
9. I liked the character that caught the fruits.

4.2.2 Apparatus

The experimental set-up is illustrated in Figure 7. The system is composed of a 60 LCD TV monitor, a laptop, and a Microsoft XBox 360 Kinect^{TM} sensor. Each child was placed in front of the screen, at the center of the Kinect's workspace. The Kinect^{TM} SDK v1.8 for Windows was used for motion tracking.

In order to measure children performance, we recorded the total number of caught objects in each sessions. To get subjective data about the system usability, preference, enjoyment, task, and game-play, a non standardized questionnaire was used (seven Likert scale). The children were also asked about the time they spend in playing video games. We also used the NASA Task Load Index (TLX) to assess the task's mental, physical and temporal demand, user's perceived performance, effort and frustration. Finally, we observed the children while performing the task and noted his/her comments, strategies and specific behaviours.

4.3 Results and Discussion

Results about performance are illustrated in Figure 8. We observed that the scores (number of fruits caught) obtained in both conditions are quite good. Indeed, we obtained a mean score of 39.18 (std : 1.1) for the C_1 condition and a mean score of 42.45 (std : 0.50) for the C_2 condition.

A statistical analysis (MannWhitney U test) revealed that the difference between the C_1 condition (no avatar) and the C_2 condition (with avatar) is not significant (U= 25.5, p-value= 0.068). However, we could consider this results as a trend and state that the avatar somehow affect the children performance.

Results revealed that the children enjoyed playing the game (6 points). We observe that the results of the main questionnaire are not significantly different between the 2 groups and are very similar for both the C_1 condition and the C_2 condition.

The children found the game interesting (5.7 points for both conditions) and stated the the game (6.0 points for the C_1 condition and 5.75 for the C_2 condition). They stated that they liked the graphics (5.7 points for the C_1 condition and 6.0 for the C_2 condition) and the sounds (5.9 points for the C_1 condition and 6.05 for the C_2 condition) of the game. The children liked the scenario (5.9 points for the C_1 condition and 5.85 for the C_2 condition), the child character (6.2 points for the C_1 condition and 6.1 for the C_2 condition).

The children who had the virtual coach had two more assertions:

- I liked the virtual coach,
- I found the coach useful.

The first question obtained in average 5.45 (std : 0.69) points overs the 7 points of the likert scale. The second question obtained in average 6 (std : 0.82).

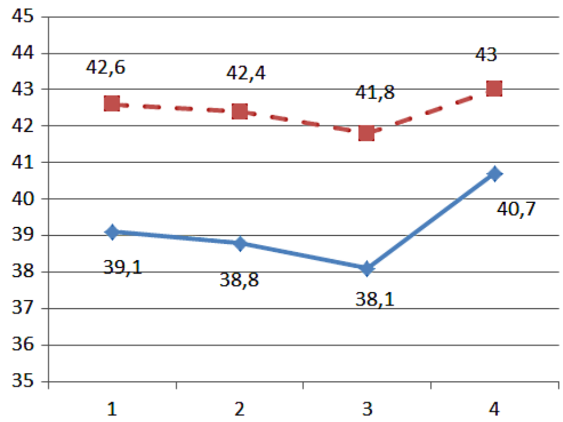


Figure 8: Number of fruits caught vs. condition C_1 and condition C_2 (dash line).

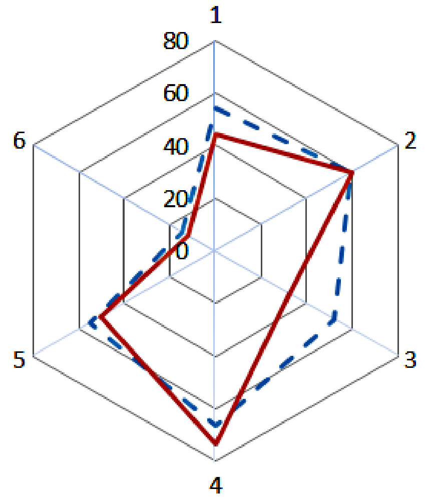
Thus, the presence of the virtual coach was very appreciated by the children. More interesting, they found it useful for the task. Observation during the experiment confirm that the children liked the avatar.

Results from the Nasa TLX questionnaire are illustrated in Figure 9 (a) and (b). We observe in Figure 9 that the results are about the same for both condition C_1 and C_2 excepted for the question 3 concerning the temporal demand where statical difference was found (U= 80, p-value= 0.04).

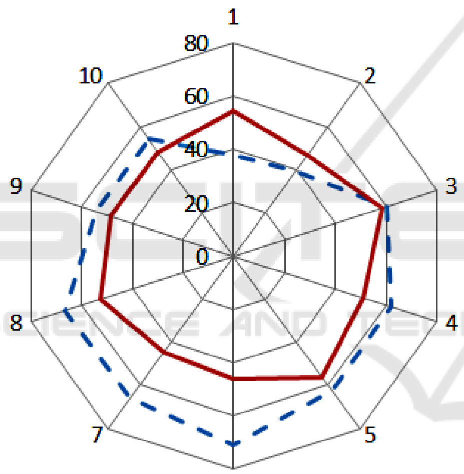
This result reveals that the children who performed in C_2 condition felt less intensity and pace in the game. Thus, the intervention of the virtual coach at the end of each session allowed the children to get some rest. Results from the NASA TLX questionnaire also reveal that the game does not involve a high mental demand. Indeed, the rating for mental demand was 44.5 (std : 15.71) for C_1 condition and 54.0 (std : 14.87) for C_2. However, and this is not very surprising, the physical demand was rated higher (about 60 for both conditions). Concerning the children performance self estimation, we observed that it was rather high for both conditions: 66.5 (std : 10.29) for C_1 condition and 73.5 (std : 10.01) for C_2. Similarly, the children felt developing rather a same level of effort: 55.0 (std : 14.72) for C_1 condition and 50.0 (std : 15.63) for C_2. Finaly, the children felt a rather low frustration at the end of the experiment: 14.50 (std : 6.43) for C_1 condition and 12.0 (std : 3.50) for C_2 condition.

5 CONCLUSION AND FUTURE WORK

In this paper, we presented VR system for the rehabilitation of children with Cerebral Palsy (CP). The



(a)



(b)

Figure 9: Results for the Nasa TLX questionnaire (dash lines correspond to the C_1 condition) : (a) rating of the 6 criteria of the Nasa TLX questionnaire, and (b) between subjects comparison.

system is non-intrusive and includes interesting characteristics such as Dynamic Difficulty Adjustment (DDA) and a control/display ratio. A Kinect^{TM} sensor allows the user to control a 3D avatar and intercept or catch and release moving objects. Furthermore, virtual coach is provided to support the child. Twenty healthy children participated in a preliminary experiment. The aim was to collect control data concerning performance and workload, and to investigate the effect of the virtual coach on both performance and subjective data. Results show a good usability of the game and reveal a high ratio of acceptance and enjoyment. In the near future, experiments with both healthy children and children with cerebral palsy (CP) will be carried out to investigate the effect of the control/display ratio on performance. The DDA protocol will be extended to integrate both behavioural and physiological data.

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