MIND – An EEG neurofeedback multitasking game

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***Abstract*— Multitasking is a prevalent phenomenon in our daily lives. Certain occupations, especially in the aviation industry, consider proficient multitasking as a key skill set in their hiring process for pilot or air traffic controller candidates. There is a growing interest in the testing and training of the multitasking ability, with in house software or commercial psychological products, usually implemented in a static task battery format. In this paper, we propose a 3D game, Multitask In Neurofeedback Driving (MIND) for training and testing of the multitasking ability. The game is developed using the Unreal 3 game engine and incorporates neurofeedback, a technique used in the training of human cognitive abilities, to further enhance the potential benefits of the training procedure. The tasks used in the multitasking condition are inspired by various psychological tests and implemented in a manner that attempts to simulate the general cognitive processes required for multitasking while driving a vehicle or piloting an aircraft. The game comes in three variants, single task condition, multitasking condition and multitasking with neurofeedback condition, for the purpose of validating the training outcomes in future studies.**

Keywords- EEG; Neurofeedback training; Neurofeedback game; multitasking; game design

I. INTRODUCTION

When one imagines a daily multitasking scenario, a common image that is conjured might be multitasking in the car. One can easily picture a driver controlling the vehicle in accordance to the road conditions, while at the same time, having a conversation with another over the phone and simultaneously, checking the GPS to ensure that he is on the correct route. Such a scenario is not uncommon for the busy working adult; perhaps it is even a daily routine for some. Such an activity is almost universally regarded as risky behavior and is even considered a traffic offence in some countries. This is because multitasking detracts the driver's focus on the road conditions, potentially increasing the risk of an accident occurring. However, given the risk involved, people still knowingly engage in multitasking in the car, as it might be necessary to do so as part of one's job requirements.

This need to multitask as a part of one's profession is fairly common, even more so in the aviation industry, where pilots and air traffic controllers have to perfectly manage a multitude of tasks simultaneously or risk potential safety hazards. Given the necessity to multitask in such circumstances, there is a growing need to study the possibilities in testing an operator's multitasking capacity and even train their ability to multitask.

II. BACKGROUND

A. Multitasking

Multitasking, although seemingly an intuitive concept, does not have a universally agreed upon definition, as research in various fields all have their own ways of defining the term [1]. Thus, there is a need to establish a definition of the type of multitasking to be used in the context of this paper. We are interested in the effect of multitasking on task performance, due to task switching, which incurs a "switching cost" [2]. If we follow the proposed "multitasking continuum" suggested in [3], our study is in line with their definition of concurrent multitasking, which defines a short period of spending seconds to minutes on one task before switching to the next task and so on. Therefore, we are interested in studying whether multitasking performance can be improved in terms of a lowered "switching cost" in tasks that have a short period between switching tasks.

B. Multitasking Tests

Testing of a person's multitasking ability is usually performed using a "task-battery" format where the subjects have to monitor a number of separate panels each with their separate task on a single screen. Performance is then scored based on the mistakes made during the test. The tests are usually simple generic tasks based on psychological tests. In study [4], the designed task battery includes 4 subtasks: arithmetic task, memory task, auditory attention, visual vigilance. In the Simultaneous Capacity (SIMKAP) test [5], the multitasking component requires subjects to perform visual item matching, answer auditory questions which can be arithmetic, making comparisons or to identify similar objects. In addition auditory questions can be asked that require checking of a calendar or telephone book, as well as questions that are required to be answered only at a future specified time. The tests can also be in the form of tasks that are simulations of the actual operational conditions for the operator. For example, NASA developed the Multi-Attribute Task Battery (MATB) that includes tasks aircraft personnel have to perform during flight [6]. The Aegis task is another example which simulates the multitasking involved in naval combat [7].

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C. Multitasking Games

Games in general require some form of multitasking, as they usually involve many things happening on the screen at the same time. The difference between those games and actual multitasking games is that multitasking games are tailored to constantly induce a specific multitasking condition on the player, with clearly defined tasks for performance monitoring, while for a generic game, as multitasking is not a central consideration, the multitasking involved follows a more random and varied nature.

Games that involve multitasking, while uncommon, have been developed in previous studies. The *Space Fortress* game [8] involves players navigating a spaceship character in a frictionless 2-D environment, avoiding and shooting the enemy fortress. The game also includes a memory task which requires players to memorize letters which indicate friend or foe that appear on mines that appear and pursue the player who is to respond accordingly. Another task is to monitor the appearance of a specific symbol and click it to receive bonus points. The *Space Fortress* game has been used in a number of multitasking studies [8-10]. Another game, *Neuroracer* [11] involves a visuomotor task of maintaining a car in the middle of a road and a discrimination task of responding to the appearance of a green circle. It has been developed for use in training of multitasking in older adults and positive results have been reported in the improvement of multitasking ability from playing the game.

D. EEG Neurofeedback

Electroencephalography (EEG) Neurofeedback is an operant conditioning mechanism on brain activity through provision of audio or visual feedback to the subject [12]. It is traditionally used for the treatment of illnesses [13] but has also been used for the improvement of performance in healthy individuals especially in cognitive ability training of sports athletes [14]. Neurofeedback has also been implemented in games as well for the training of cognitive abilities [15]. This makes it a promising method to include in a multitasking game to further enhance the training benefits that can be gained from playing the game.

III. Materials And Methods

A. Game Design

The game is developed in the Unreal 3 engine with the Unreal Development Kit (UDK). The game is designed as a 3D driving game based on the basic cognitive processes required in the familiar multitasking scenario of driving a car, having a conversation and ensuring that one is on the correct route. We can simplify having a conversation to an auditory response task and the route checking to a memory recall task. The driving itself can be implemented as a simple driving game in the game engine, where the player has to control the vehicle along a straight path, made up of individual road "segments" while avoiding obstacles. The driving is simplified such that the player is only required to perform the left and right motions, with the forward velocity being controlled by the game. The player is required to avoid a number of obstacles, placed randomly, on each segment of road during the test.

For the two other tasks, we take inspiration from previously reviewed multitasking tests [4, 5] and their underlying psychological tests to design them. For the auditory task, we used a modified oddball task, where the subject has to determine whether the sound played is a target or non- target and respond accordingly. For the memory task, we utilize a simple cued recall task, where the subject has to remember a set of random letters at the start of the test, and during the test, letters will be shown, one at a time and the player has to respond whether the shown letters are part of the memorized set or a novel stimuli. For both tasks, the player is to respond promptly, within a defined time frame to register as a correct response. The tasks involved and their descriptions are shown in Table 1.

The game shall have different difficulty settings which increase the demand in each of the separate tasks. 3 such difficulty levels are proposed. For the driving task, a higher difficulty increases the number of obstacles in each segment of road. For the auditory task, a higher difficulty increases the similarity of the two audio clips. For the memory task, a higher difficulty increases the number of letters the player has to memorize. The way the difficulty modifies the tasks are shown in Table 1.

The game shall also have 4 different modes of play. First is the base game, comprising of all tasks without neurofeedback. Second, the base game with neurofeedback included. Next, the game with just the driving task alone, and lastly the game with just the driving task alone but with neurofeedback. The proposed variants are summarized in Table 2.

Multitasking performance is determined within the game through a scoring system where the performance of each individual task is scored based on the percentage number of errors committed over the total number of trials. Then, each task contributes equally to determining the final multitasking score, by comparing the performance of each individual task, and based on the lowest scored task; introduce a multiplier to the summation of the scores from the 3 tasks. The proposed scoring method is shown in Table 3.

TABLE I. DESCRIPTION OF TASKS AND DIFFICULTY MODIFICATION

Task	Description	Difficulty Modifier		
		Easy	*Normal*	*Hard*
Driving	Avoid randomly configured obstacles on each road segment	2 or 3 per segment	3 or 4 per segment	4 per segment
Audio	Determine if audio clip played is the target stimuli	Diffirent audio files	Same audio file, 50% pitch similarity	Same audio file, 75% pitch similarity
Memory	Determine if letter displayed is part of a set of letters memorized earlier	Memorize 3 letters	Memorize 4 letters	Memorize 5 letters

TABLE II. PROPOSED VARIANTS AND THEIR FEATURES

Game Variant	**Include the following Tasks/ Features**			
	Driving	***Audio***	***Memory***	***Neurofeedback***
Base	Yes	Yes	Yes	No
Base with Neurofeedback	Yes	Yes	Yes	Yes
Single Task	Yes	No	No	No
Single Task with Neurofeedback	Yes	No	No	Yes

TABLE III. SCORING

Task	**Scoring Description**		**Calculation of Individual Task Score**	**Calculation of Multitasking Performance**		
	Correct Trial	***Incorrect Trial***				
Driving	No collision within a segnment	1 or more collisions within a segment				
Audio	Correct response within the time limit	Incorrect response or over the time limit	(Correct Trials/Total Trials) x 100	Any Task Score ≤ 50	Any Task Score between 51 and 75	All Task Scores > 75
Memory	Correct response within the time limit	Incorrect response or over the time limit				
Multiplier				0.5	1	2

B. Neurofeedback Implementation

Neurofeedback is implemented in the game with the use of the Emotiv EPOC EEG headset. The Emotive EPOC has a sampling frequency of 128 Hz and 16 bit A/D resolution. The device is chosen as it is convenient to set up and gives comparable performance to a conventional device [16]. The Emotiv EPOC has 14 electrodes positioned at AF3, F7, F3, FC5, T7, P7, O1, O1, P8, T8, FC6, F4, F8, AF4, according to the 10-20 international system [17]. When the game is played, raw EEG signals are transmitted to the computer via Bluetooth and EEG data is processed online to determine whether the player is in the desired brain state. This information is sent to the game software and the game alters the speed of the player's car as the form of neurofeedback. If the player is in the desired state, the car moves noticeably faster. If not, the car noticeably slows down. This functionality also serves to accommodate the ability of the player as a form of adaptive training. If the player is comfortable with the tasks and achieves the desired brain state, the neurofeedback allows the game to increase the speed of the car to provide a slight challenge for the player. If not, the game reduces the speed of the car to make the game less demanding until the player is comfortable and in the desired brain state. The aim for the inclusion of such a mechanism is to further improve on the possible training benefits that can be gained from playing the game. The neurofeedback algorithms to be used follow that described in a previous work [18]. Different training protocols, such as EEG alpha, theta/beta power ratio and fractal dimension based training can be implemented.

IV. RESULTS AND DISCUSSION

The final game was developed according to the design guidelines described in the previous section. A screenshot of the final game is shown in Fig. 1. It shows the driving task, avoiding the obstacles on the road, and the cued recall memory task, where a letter is displayed slightly above the center of the screen. The audio task cannot be shown visually but the response procedure is similar to the memory task: press a key based on the audio clip played.

In order for validation studies on the effectiveness of the training paradigm, to be carried out, variants of the game are designed. They are the base game with neurofeedback, the base game without neurofeedback, and the driving task alone, with and without neurofeedback. With these variants, user studies can be conducted to determine the usefulness of the inclusion of neurofeedback within the multitasking game and to validate whether performing a multitasking activity does indeed improve multitasking performance as opposed to just playing the single task condition. We can also include a no game control group to verify the findings.

Different levels of difficulty are also included in the final design by adding some variations to the original design. To test the multitasking performance after training, we propose 2 methods. First, we can use a previously unseen level of the multitasking game which the players were not trained on. For example, if players were trained on the "normal" difficulty, we reserve the "hard" difficulty solely for testing purposes. This would test for improvement in skills specific to this particular multitasking condition. Secondly, we can employ a separate multitasking test, such as the SIMKAP test or the MATB test to test for improvements in multitasking performance. This can test the subjects' improvement in general multitasking ability. We propose a user study over a period of one month for 5 groups of subjects. The proposed training-testing protocol is displayed in Table 4.

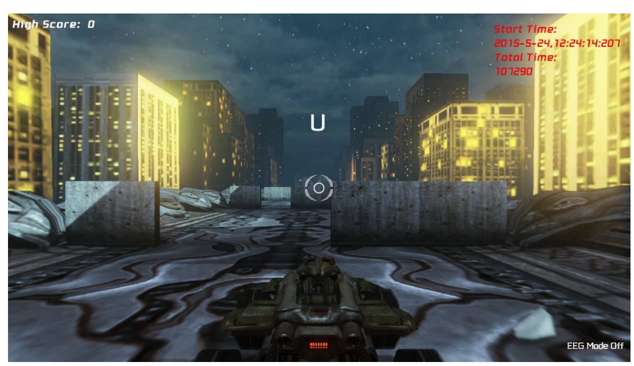

Figure 1. Screenshot from the final game, showing the driving task and the memory recall task with the letter "U" displayed.

TABLE IV. PROPOSED TESTING / TRAINING SCHEDULE

<table>
<tr><th rowspan="2">Study Group</th><th colspan="5">Schedule</th></tr>
<tr><th>Pre-Train</th><th>Week 1-2</th><th>Mid-Test</th><th>Week 3-4</th><th>End-Assesment</th></tr>
<tr><td>Base</td><td rowspan="5">Play game on “hard” difficulty and SIMKAP</td><td rowspan="4">Train with respective gametype on “normal” difficulty, 2 sessions of 1 hour / week with breaks</td><td rowspan="5">Play game on “hard” difficulty and SIMKAP</td><td rowspan="4">Train with respective gametype on “normal” difficulty, 2 sessions of 1 hour / week with breaks</td><td rowspan="5">Play game on “hard” difficulty and SIMKAP</td></tr>
<tr><td>Base with Neurofeedback</td></tr>
<tr><td>Single Task</td></tr>
<tr><td>Single Task with Neurofeedback</td></tr>
<tr><td>No Game</td><td>-</td><td>-</td></tr>
</table>

As we are interested in determining an overall score for multitasking performance, we decided that all tasks, the driving, audio and memory tasks should share equal weightage in terms of contributing to the overall multitasking score. This is because we feel that no emphasis should be placed on any one task. In an ideal multitasking scenario, we should require all tasks to be performed as perfectly as possible. This is similar to how the SIMKAP test determines multitasking performance [5]. However, if an emphasis on a primary task is required, it is a simple matter to change the scoring metric to suit the requirements. The score for each task are calculated separately and taken over the total number of trials to get a task performance percentage.

Generally, to determine the “switching costs” one would first perform a single task test and record the subject’s performance for the task, followed by a multitasking test and record performance in that same single task. Comparing the two, one would be able to quantify switching cost in terms of performance degradation within the single task. However, in our game, we make the assumption that the tasks by themselves are simple and subjects should have near to perfect performance in the single task condition. Hence, we calculated the performance by taking correct number of trials over all trials within a single game session.

V. CONCLUSION

In this paper, we proposed a method for training and testing of multitasking ability, using a 3D multitasking game developed based on psychological tests. Neurofeedback is implemented within the training mechanism with the hypothesis that neurofeedback would improve the possible training benefits to the multitasking ability, above what can be attained from just playing the multitasking game alone without neurofeedback. A proposed user study with 5 study groups would be conducted in the future to validate the game as a tool for training and testing the multitasking ability, and if neurofeedback improves on the possible gains from training.

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