ANALYSIS OF MULTIMODAL INTERACTION METHODS FOR SIMULTANEOUS SPATIAL AND COGNITIVE TASKS

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Abstract

With the advent and increasing popularity of new methods of Human Computer Interaction (HCI) such as eye-tracking, speech and gesture interaction modes, comes the question of the benefits these input modes bring. This project aims to study how multimodal interaction methods can reduce the overall workload and improve performance of the user whilst interacting with complex systems.

The objective of the project was to compare several combinations of input methods and their effect on the overall workload and performance of the user whilst simultaneously performing 2 spatial tasks and 1 cognitive task.

To achieve this, a simulation was developed as the experimental platform. The simulation recreates a combat situation that would require users to defend themselves and attack hostile targets, both of which required spatial localization. Changing of ammunition types, a cognitive task, was also added to increase the difficulty of multi-tasking.

An experiment involving 12 participants across different age groups was conducted with 3 distinct interaction modes, assigned in random order. The first interaction mode is operated via mouse and keyboard; the second employs touch-screen, keyboard, and speech input; and the final interaction mode involves eye-tracking, keyboard, and speech input.

1.0 Overview

This project is a component of the Research@YDSP module and is a collaborative effort between a team of students from Hwa Chong Institution and DSO National Laboratories.

The project aims to study how the use of multimodal interaction involving a variety of input modes can possibly decrease the overall workload of the user whilst he simultaneously performs concurrent tasks, more specifically 2 spatial tasks and 1 cognitive task.

1.1 Objectives

The objective of the study is to design and evaluate alternative interaction modes that can be used to efficiently perform concurrent tasks on a virtual system. The evaluation would also examine the effectiveness of the combination of various interaction modes in addressing the workload and performance of the participant whilst performing the concurrent tasks.

Interaction modes studied within the project are touch-screen, speech and eye-tracking.

1.2 Hypothesis

The following hypotheses have been adopted for the course of the study;

1) When compared to the mouse and keyboard control, a multimodal approach would result in reduced overall workload of the user performing concurrent spatial and cognitive tasks.
2) A multimodal approach would result in a better performance involving the aforementioned concurrent task, as compared to the mouse and keyboard control.

1.3 Methodology

The project commenced with a literature review to understand various interaction input modalities as well as the principles governing their application.

Following this, a representative simulation in the form of a game was developed in Adobe Flash that encompassed the spatial and cognitive tasks that the participant would have to perform concurrently.

Meanwhile, the team brainstormed various combinations of input modes that would feasibly provide participants with an effortless and intuitive multimodal interaction experience.

Lastly, an experiment was conducted to evaluate the various designs. The experiment which involved 12 participants collected both quantitative and qualitative data that was then analysed and reported within this document.

2.0 Design Solutions and Interaction Concepts

2.1 Concurrent Spatial and Cognitive Tasks

The experiment simulates a scenario which required users to control a tank, defend themselves and attack hostile targets using different ammunition types.

The user was required to use keyboard keystrokes to control the tank turret, while alternative interaction methods, namely touch, eye-tracking and speech interaction, were used to control a defensive shield and change ammunition. It was hypothesized that use of alternative interaction modes would improve performance, reduce user workload and be better-received.

Mouse interaction was used as a baseline against the other forms of input. In this experiment, the shield would be directed by the mouse cursor.

Touch interaction was employed as it is expected to be more intuitive due to the direct mapping of gestures with the virtual information.. With the advent of touch screen smartphones, participants would also have been more accustomed to it. With this interaction method, the shield would point towards the direction of the participant's touch. Participants could also direct the shield by dragging it.

In earlier work, we discovered that eye-tracking was faster and more intuitive for targeting tasks. Eye-tracking interaction was also thought to be faster and more intuitive since participants would naturally be looking at the targets they wanted to shield against. This is supported by previous research which states that "the user's gaze is often already fixated on the target long before the cursor homes in" (Alonso R. et al., 2013). Due to the "Midas Touch" issue as documented by Robert Jacob, eye-tracking interaction required slightly different controls to operate effectively. Instead of having the shield constantly point towards where the participants were looking at, participants needed to explicitly lock the shield to synchronize their gaze using either the keyboard or speech. If the eye-track position is tracked constantly by the shield, the shield would be moving about unintentionally. This would result in increased mental demand, since participants would have to be conscious of where they are looking at (Jacob, R. J., 1995).

Speech was made available as a redundant control option to study if participants would prefer an additional input mode, whether it would overload the user, and to gather more information on how users would handle more interaction modes. It was noted in a user study by Carnegie

Mellon University (1989) that people preferred a multimodal combination of speech in conjunction with other interaction methods as compared to speech or gestures alone.

2.2 Simulation Design & Mechanics

The simulation employed during the experiment replicates tasks where participants had to react to representative battlefield situations in a limited amount of time. Participants were Q. Screenshots of the simulation are shown in Figure 1.

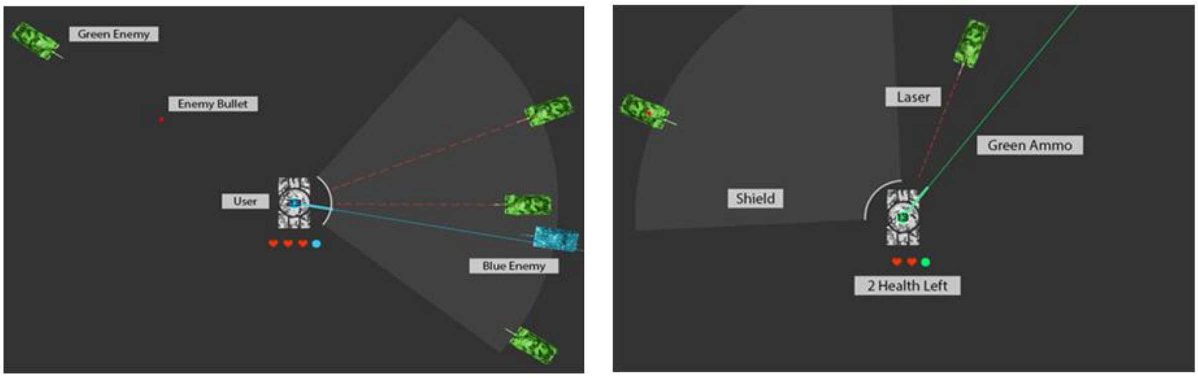

Figure 1: Screenshots of Experiment Simulation

Map: A top-down view with the participant represented in the centre with enemy approaching from all sides was adopted. Enemies set up positions around the user. The background is dark gray to contrast all other elements with bright colours as seen above.

Health: Each participant has 3 lives represented by red coloured hearts directly below the player's tank that will decrease by 1 every time it is shot. There is an audio feedback to alert the user that they are shot and no other visual feedback as it would be distracting.

Targeting: 2 types of enemies are present in the simulation - blue and green. Participants have to change ammunition type when engaging different coloured enemies. Ammunition is changed by pressing the `W` key or speaking "ammo" or "change", the colour of the user's turret will change to the respective colour. Rounds fired will also reflect ammunition selection. A line is extended from the turret to the end of the viewport which allows the participant to predict the trajectory of their round to the target.

Shield: The shield which is white in colour extends outwards for the user to identify the range of the shield. There is no other audio or visual feedback, for fear of distraction. The shield is synced with the position of the cursor or tap (for touch screen).

Lasing: Before enemies fire at the player, they will laser target the player's tank for 1s before firing a round to allow time for the participant to move the shield. Enemy bullet and lasers have the same colour (red) as the player's health to associate the colour with its effect on the user's lives.

Turret: Users could control their shield using the various interaction modes, while aiming the turret with keys A and D. Minute acceleration and deceleration was implemented for smooth aiming. As these keys translate into counter-clockwise and clockwise rotations respectively, it is foreseeable that users might map the keys as left/right instead. However, the user can quickly diagnose and recover from the error after realizing the correct mapping of gestures.

Firing: To encourage precision "aiming", the user can only fire 3 consecutive rounds before it requires a time penalty of 2s to recover. The turret and laser will turn red during the time penalty to represent the "Cooling down" of the system. Participants can fire with `SPACE` key or say "shoot" or "fire" to fire a round.

Pace: The optimal strategy for the game is to quickly eliminate the closest enemy while shielding against shooters, in order to prevent being swarmed by enemy tanks. Thus, the user is required to actively control both the turret and shield. Enemies were designed to appear every 4s while a 360° turn of the turret requires about 6s. This means that users have to quickly determine the direction with which to attack the enemy.

3.0 Experimental Procedures

3.1 Trial Procedures

Trial participants were required to perform the simulation task 3 times, with a different interaction method adopted each time. The 3 interaction modes are: Mouse with keyboard, Touch-screen with keyboard and speech recognition, and Eye-tracking with keyboard and speech. Participants would first be allowed a 2 minute practice session to familiarize with the interaction mode before the actual experiment.

The sequence in which the participants experienced the simulator was randomized to ensure unbiased data collection. Quantitative data in the form of task completion time and accuracy rate was collected for analysis. Qualitative feedback and observations were also recorded.

3.2 Experimental Setup

3.2.1 Hardware and Software requirements

Hardware Requirements	**Software Requirements**
1) Laptop (with at least 1 USB 3.0 port and 3 USB ports) 2) EyeTribe eye tracker (requires USB3.0) 3) 27" Planar Systems Multi-touch Surface 4) Mouse & keyboard 5) Headphones with microphone	1) I-Focus console app (EyeTribe) 2) Dragon NaturallySpeaking speech recognition software 3) Adobe Flash Game (simulation)

3.2.2 Measures

Quantitative Measures: Quantitative data in the form of task completion time (time taken to complete the task) and accuracy rate (percentage of bullets that missed targets) was collected.

Qualitative/Subjective Measures: Qualitative data was recorded via the Questionnaire for User Interaction Satisfaction (QUIS) and the NASA Task Load Index (NASA-TLX). Participants had to use QUIS to rate the design concepts based on their experience with them. Participants also had to complete a NASA-TLX questionnaire to rate their perceived workload experienced. The trial concluded with an interview to verify participant observations and comments.

3.3 Trial Participants

12 participants aged between 16 and 40 inclusive were involved in the trial. None of the participants had prior experience with the simulation. However, 1 participant had undergone pilot training and 5 other participants were avid gamers.

4.0 Observations and Findings

4.1 Concurrent Spatial and Cognitive Tasks Findings

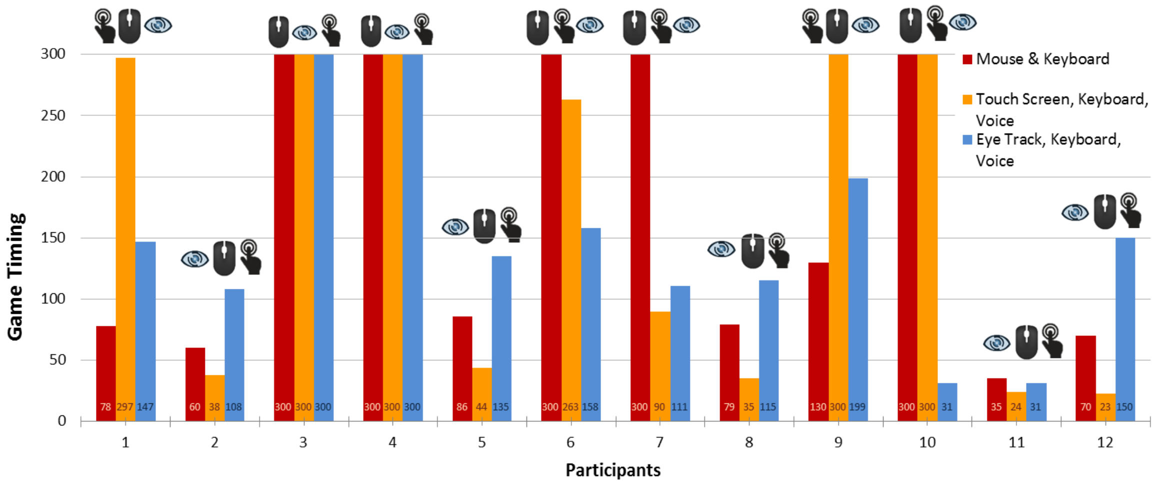

Figure 2: Task Completion Time for Concurrent Tasks and Ranking of Interaction Modes

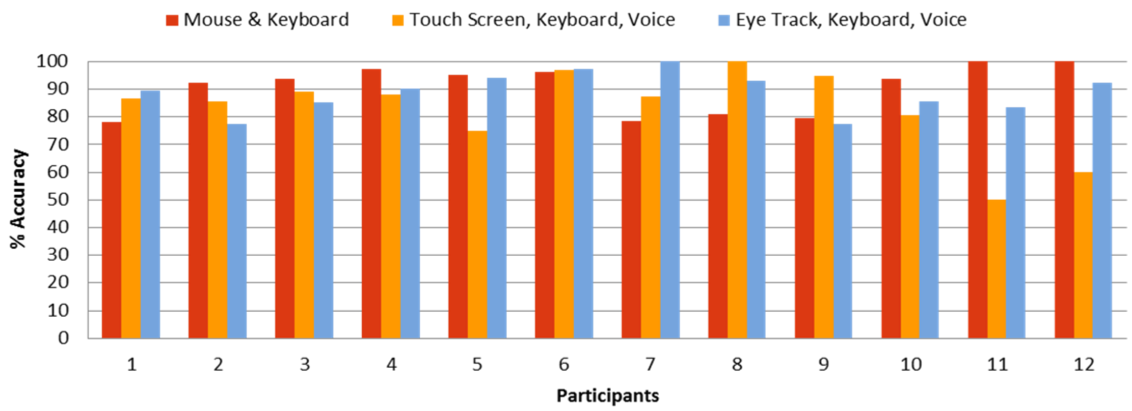

Figure 3: Accuracy Rates (Percentage of Targets Hit)

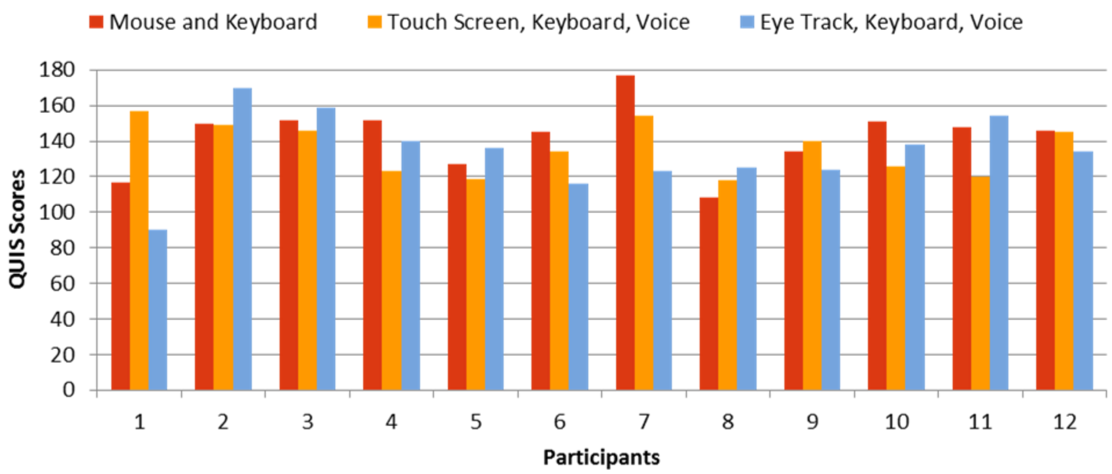

Figure 4: QUIS Scores

Figure 2 above shows task completion time data collected for each participant during the experiment. The icons located above represent the individual participant's preference for the interaction modes experienced; the finger icon represents touch interaction, the mouse icon represents mouse interaction whilst the eye icon represents eye-tracking interaction.

After participants played the game, the time taken to complete the task, accuracy rate and ranking of each participant's preferred interaction mode was collected. The mouse, touch screen and eye-tracking interaction methods had a mean timing of 169.83, 167.83 & 148.75, and an accuracy rate of 90.4, 82.9 & 88.8 respectively (higher the better).

Out of 12 participants, 5 ranked mouse and keyboard as their preferred interaction mode, while 5 ranked eye-tracking, keyboard and speech as their preferred interaction mode. The remaining 2 participants ranked touch, keyboard and speech as their preferred interaction mode. The mean ranking for mouse, eye-tracking and touch interaction are 1.67, 2.00 and 2.33 respectively.

Some participants were able to reach the maximum duration of 300 seconds before they were stopped. With mouse interaction, 5 participants achieved this limit. All 5 ranked the mouse as their first choice. With touch interaction, 4 participants reached this limit, with one ranking it as his first choice, another as his second and the remaining 2 as their last. For eye-tracking interaction, 2 participants achieved this limit, with both choosing it as their second choice.

4.1.1 Mouse Interaction

It was an expected outcome where interaction with the mouse fared well. This is because participants have had prior experience to the mouse and keyboard control and found the mouse more accurate and precise.

It was observed that the mouse yielded the best timings for many participants, with the best mean timing of 169.83 sec. 5 out of 12 participants preferred this interaction mode.

4.1.2 Eye-Tracking Interaction

It was interesting to note that despite the limitations of the eye-tracking device, eye-tracking interaction was still well-received and performed relatively well for the task.

Some participants commented that eye-tracking was more intuitive compared to mouse and touch interactions as they found it convenient to lock their shield to the enemies which they were already looking at. 5 out of 12 participants preferred this interaction mode. However, some participants commented that the eye-tracker was not accurate and the cursor localization seemed unstable. Nevertheless, they found eye-tracking quick and intuitive. It was also interesting to note that one participant found eye-tracking so intuitive that he was not aware that the shield was actually directed by his eyes!

The participants who started off playing this mode first did relatively well compared to other participants who started off playing other modes first. This could imply easy learning, but this is contradictory to the QUIS results and comments for this mode. A possible explanation is that eye-tracking and particularly the special controls required was new to most participants, although eye-tracking itself could be an intuitive and easy-to-master interaction mode.

4.1.3 Touch Interaction

It was originally expected that the touch interaction mode would be most effective and intuitive due to the direct and instantaneous mapping of touch gestures with the virtual content. However, participants seemed to find touch interaction less favorable as compared to the other interaction modes, with 2 out of 12 participants preferring this interaction mode.

Unlike previously predicted, fatigue did not play a substantial factor in performance, although some participants did comment that if they were to use touch interaction longer, fatigue could potentially set in. Rather, participants commented that the touch screen and particularly speech input was unresponsive, and that their hand often occluded incoming enemies. Participants who started the experiment by playing the touch-screen version first fared the worst with this mode. This implies a steeper learning curve, and difficulty in mapping the functions.

Nevertheless, touch interaction performed quite well in terms of task completion, lagging closely behind the mouse. It had the second best mean timing of 167.83 seconds, with 4 out of 12 participants exceeding the 300 second limit. This is compared to the mouse with a mean timing of 169.83 seconds and with 5 out of 12 participants exceeding the 300 second limit.

4.2 User Workload Findings

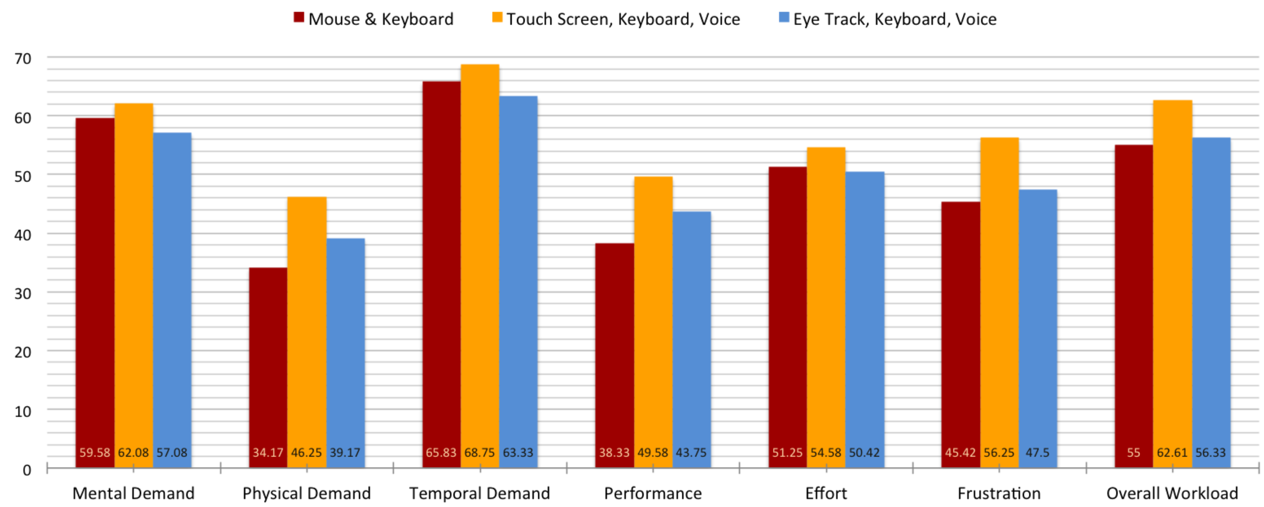

Figure 2: Mean NASA-TLX Scores

After the participants had completed the game, they were asked to fill in a NASA-Task Load Index (NASA-TLX) survey. The objective of this survey was to qualitatively measure the various aspects of workload that participants experienced in the progress of playing the game. Factors included mental demand, physical demand, temporal demand (time induced urgency), performance (how well he felt he performed), effort required and frustration levels.

It was interesting to note that although the mouse performed better than the eye-tracking interaction mode in terms of timing and ranking, eye-tracking resulted in a lower mental and temporal demand, and also required less effort than the other 2 interaction modes. However, the mouse still resulted in the lowest physical demand and frustration levels, as supported by participant’s comments. It also resulted in the lowest overall workload, with eye-tracking lagging closely behind. Touch interaction on the other hand resulted in notably higher workload scores for all aspects, particularly for frustration and physical demand. This is supported by participant’s comments and the poorer timing and ranking for touch interaction.

5.0 Discussions and Recommendations

5.1 Overview

Experimental results showed that participants favored the mouse for its accuracy and ease of learning. Still, it was observed that the mouse outperformed eye-tracking interaction in terms of ranking and timing by only a slight margin. A substantial number of participants preferred eye-tracking over mouse interaction as they found it to be more effective and intuitive.

It was also observed from the NASA-TLX results that eye-tracking interaction shows reduced mental workload and effort as compared to the mouse interaction. However, mouse interaction shows reduced physical demand and overall workload, and lower frustration levels. Touch interaction resulted in a notably higher workload scores for all aspects. It also performed the worst in terms of timing and ranking.

5.2 Concurrent Tasks and User Workload Findings

5.2.1 Mouse Interaction

Results show that the mouse and keyboard may be the best input method for simultaneous spatial tasks. This could be due to participants' prior experience with this input mode, resulting in ease of learning as observed during the experiment. There are few physical constraints for these devices in the areas of accuracy and usability, which puts them at an advantage. Participants performed best with this interaction mode for timing and ranking.

With reference to workload ratings, mouse interaction was observed to have the least physical and overall workload scores. However, data shows that higher mental and temporal workload demand for mouse interaction as compared to eye tracking.

Nonetheless, it was surprising that the mouse did not substantially outperform the other interaction modes.

5.2.2 Eye-tracking Interaction

Eye-tracking interaction is a new form of interaction for most participants, with several limitations pertaining to accuracy of the device, resulting in preference for other interaction modes instead. Advantages of this interaction were its intuitiveness and usability.

Observations made during the experiment allowed the team to infer that eye-tracking was intuitive as participants did not have trouble locking the shield to the correct location. A possible reason for this decision is that participants found it difficult to coordinate both hands to press 2 keys at once. This shows the benefit of multimodal interaction as it allows for more effortless coordination between different parts of the body.

With reference to workload rating data, this interaction resulted in the least mental and temporal demand, and required least effort. A possible reason is that since participants were already looking at their targets, it was less mentally demanding and more intuitive for them to move the shield to the enemy, reducing mental workload and effort. This is supported by participant's comments that eye-tracking felt 'faster' and more 'convenient'. However, it was noted that eye-tracking did not reduce physical demand as was expected since participants only had to look at their target and either activate the lock with the keyboard or their voice. It was also reported that participants found it straining on their eyes because the inaccuracies of the eye-tracker required them to focus on their targets more intensely. This is evident from the relatively high standard deviation for physical demand, hinting that physical demand could be attributed to poor device calibration. It was also noted that eye-tracking reduced temporal demand, which supports the notion that eye-tracking is inherently faster.

Interestingly, this input method had the lowest standard deviation in terms of both timing and percentage accuracy, implying consistent performance for this interaction mode.

5.2.3 Touch Interaction

Touch interaction is fairly similar to the mouse interaction as both require the same set of motor skills and are very 'hands-on'. It was predicted that participant's prior experience with smartphones would lead to ease of learning. However, this method pales in comparison to the mouse interaction in terms of ranking although it was previously thought to allow users to better map the shield to its intended position. Furthermore, it was observed that touch interaction had considerably higher workload in all aspects, particularly for physical demand.

There are several reasons for this. Firstly, the touch screen was unresponsive at times. Secondly, participants felt that the touch screen and keyboard didn't go well together. They felt it was better to use multi-touch controls instead, a possible area of future research. Thirdly, participants also found that their hand sometimes obstructed their view of the screen, making it harder to locate enemies. Some participants took up the strategy of taking their hands away from the screen immediately but this resulted in increased effort and physical demand. Participants also need to do so while controlling the keyboard, making the process unintuitive, resulting in increased mental demand.

5.2.4 Speech Input

Participants were observed to have preferred executing only 1 function using speech input. Some participants were able to use speech to execute 2 functions, but none of the participants executed all 3 functions (ammo, lock and fire) using speech input.

Also, it was observed that 3 out of 12 participants opted not to use speech input as they found it unresponsive. Nevertheless, many participants found speech input useful as they could now distribute the workload to another part of their body (speech instead of only hands).

It was observed that the "fire" command was not frequently used. A possible reason is that participants found it tiring and unwise to continuously say "fire" given the time lag. Instead, they preferred to use the "ammo" command to change ammunition type as ammunition change was a less frequent task. However, for eye-tracking, participants preferred to use speech input to lock the shield rather than to change ammunition.

It was documented by Jones, Hapeshi and Frankish (1990) that participants tended to treat the computer as human. Thus, participants changed their tone and voice in times of frustration or anxiety, swapped words of similar meanings and expected the computer to understand them. Hence, accuracy and redundancy is crucial for users to readily accept speech input as effective and intuitive. It was additionally observed that participants mostly interchanged "ammo" and "change" as compared to other commands. A possible reason for this is that participants would have found it more natural to use "change ammo", but the speech recognition software limited them to only be able to say one word at a time. They thus found it natural to interchange the 2 words, especially when they were frustrated.

5.3 Interaction Design

With regards to the simulation, some participants commented that using keystrokes, `A` and `D` was not optimal for steering the turret. Participants confused the clockwise/anti-clockwise motion of the turret, thinking of it as left and right as the keys had implied. Participants also found that mapping the `W` key for changing of ammo was unintuitive and physically straining, as the `W` key is usually used for moving forward or jumping.

When introduced to multiple input devices, participants felt that it was good that they were able to allocate a single input device to execute a single function. Some commented that it was easier for 'one part of the body to control one thing'.

With regards to multi-tasking, participants demonstrated varying abilities to learn quickly. However, it was noted that they sequentially, rather than simultaneously, tackled multiple tasks. The team believes that to improve multi-tasking such that it becomes effortless, interaction designs should work towards simplifying a task as much as possible, since better mapping of functions are not necessarily beneficial.

Participants proposed that multi-touch interaction should be used over the combination of keyboard and touch interaction, as this would make it more effective and intuitive.

6.0 Future Work

6.1 Learning Effect

It was clear that the learning effect played a substantial role in this experiment. A larger and longer study involving extended training may be conducted so as to completely eradicate any unfair advantages or disadvantages to do with user learning abilities for the input methods.

6.2 Multi-touch input

Feedback included a displayed interest towards using solely touch screen to handle simultaneous tasks. A study with the relevant hardware and software could be conducted to investigate the viability of this input method.

7.0 Conclusion

The multi-modal input methods studied have shown unique characteristics. Eye-tracking is a speedier, more intuitive and mentally comfortable, but more physically demanding input method. Its ranking, timing and overall workload is comparable to that of the mouse and keyboard, which is extremely promising, given the fact that eye-tracking is a new and unconventional input method to most users, making them unaccustomed to it. Furthermore, it is predicted that with a more accurate and powerful eye-tracker, physical demand and even overall workload can be substantially reduced.

Touch-screen and keyboard, on the other hand, does not seem like a feasible combination of interaction. Theoretically, it should have been easier to map out the functions using this input method, but experimental data and observations have shown otherwise. Nevertheless, we have yet to experiment with multi-touch input, which could prove to be more promising than the current touch screen and keyboard interaction method.

The team would thus like to suggest that the multimodal combination of Keyboard and Eye-tracking with speech input would be most suitable for performing concurrent tasks, whilst allowing for reduced user workload. However, one must note that an eye-tracker and speech recognition software of considerably better accuracy and quality would be required. The reason for this choice is due to the fact that this interaction method was found to be faster and more intuitive, yet allowed for reduced effort, mental and temporal demand. Furthermore, the shortcomings of eye-tracking has been predicted to be due to the inaccuracies of the devices and steep learning curve, both of which can be mitigated with better devices and training.

8.0 References

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9.0 Appendix

9.1 Raw Data (QUIS)

	Mouse and Keyboard				
Participant	1: Overall User Reactions	2: Screen	3: Terminology	4: Learning	Overall Score
1	23	48	12	34	117
2	35	54	16	45	150
3	36	48	16	52	152
4	33	48	16	55	152
5	32	42	13	40	127
6	32	45	17	51	145
7	43	54	17	63	177
8	27	37	12	32	108
9	32	39	14	49	134
10	39	47	15	50	151
11	39	47	16	46	148
12	34	48	16	48	146
Mean	33.75	46.417	15	47.083	142.25
Mode	32	48	16	-	152
Median	33.5	47.5	16	48.5	147
Min	23	37	12	32	108
Max	43	54	17	63	177
Std Dev	5.379	5.143	1.809	8.649	18.341

	Touch Screen, Keyboard, Voice				
Participant	1: Overall User Reactions	2: Screen	3: Terminology	4: Learning	Overall Score
1	43	54	18	42	157
2	33	52	16	48	149
3	35	48	13	50	146
4	28	46	16	33	123
5	28	41	14	36	119
6	30	43	13	48	134
7	34	52	16	52	154
8	27	39	12	40	118
9	34	42	14	50	140
10	23	43	14	46	126
11	31	48	15	26	120
12	32	48	16	49	145
Mean	31.5	46.333	14.75	43.333	135.917

Mode	28	48	16	48	-
Median	31.5	47	14.5	47	137
Min	23	39	12	26	118
Max	43	54	18	52	157
Std Dev	5.036	4.812	1.712	8.094	14.375

	Eye Track, Keyboard, Voice				
Participant	1: Overall User Reactions	2: Screen	3: Terminology	4: Learning	Overall Score
1	23	40	11	16	90
2	43	54	17	56	170
3	39	52	15	53	159
4	31	48	16	45	140
5	36	42	14	44	136
6	27	46	12	31	116
7	25	51	14	33	123
8	30	41	12	42	125
9	33	31	14	46	124
10	32	42	13	51	138
11	40	47	16	51	154
12	31	48	16	39	134
Mean	32.5	45.167	14.167	42.25	134.083
Mode	31	48	16	51	-
Median	31.5	46.5	14	44.5	135
Min	23	31	11	16	90
Max	43	54	17	56	
Std Dev	6.098	6.351	1.899	11.258	21.189

9.2 Raw Data (NASA-TLX)

	Mental Demand		
Participant	Mouse & Keyboard	Touch Screen, Keyboard, Voice	Eye Track, Keyboard, Voice
1	13.3	9	24.975
2	17.355	14.685	9.345
3	23.31	17.355	10
4	6	8.645	8.01
5	9.345	18.69	9.345
6	14.985	8.645	15
7	13.32	13	18.69
8	23.31	21.645	17.355
9	7.315	13.35	11
10	16	0	18.69
11	24.975	29.97	24.975
12	3.35	7.315	6.65
Mean	14.38041667	13.525	14.50291667
Max	24.975	29.97	24.975
Min	3.35	0	6.65
Std Dev	7.090490577	7.798394648	6.41273607

	Physical Demand		
Participant	Mouse & Keyboard	Touch Screen, Keyboard, Voice	Eye Track, Keyboard, Voice
1	8.01	3.015	26.7
2	0	0	1.005
3	0	0	0
4	3.325	0	2.01
5	0	0	0
6	8.01	22.695	0
7	8.01	18.69	14
8	0	0	0
9	0	3.685	3.685
10	0	29.97	2.68
11	0	0	3.015
12	0	0	0
Mean	2.279583333	6.504583333	4.424583333
Max	8.01	29.97	26.7
Min	0	0	0
Std Dev	3.582507031	10.77680262	8.027615535

	Temporal Demand		
Participant	Mouse & Keyboard	Touch Screen, Keyboard, Voice	Eye Track, Keyboard, Voice
1	6.7	7	3.015
2	29.97	28.305	24.975
3	18.69	19.98	14.985
4	8.01	13.35	7
5	14.985	24.975	14.985
6	12	4.69	31.635

7	3.99	26.64	23.31
8	18.69	17.355	21.645
9	18.315	16.65	18.315
10	22.695	5.36	28.305
11	18.69	24.03	16.02
12	28.305	28.305	28.305
Mean	16.75333333	18.05333333	19.37458333
Max	29.97	28.305	31.635
Min	3.99	4.69	3.015
Std Dev	8.108664091	8.830320527	8.704797909

	Performance		
Participant	Mouse & Keyboard	Touch Screen, Keyboard, Voice	Eye Track, Keyboard, Voice
1	6.7	15	15
2	9.31	9.31	4.655
3	3.33	1.995	1.33
4	8.325	13.32	11.655
5	6	13	2.345
6	0	8	2.345
7	0	9.31	0
8	10.64	8.645	8.645
9	7.315	5.985	0
10	1.675	5.32	9.975
11	1.995	3.99	3.325
12	3.99	2.68	1.675
Mean	4.94	8.04625	5.079166667
Max	10.64	15	15
Min	0	1.995	0
Std Dev	3.624938871	4.240605727	4.989057951

	Effort		
Participant	Mouse & Keyboard	Touch Screen, Keyboard, Voice	Eye Track, Keyboard, Voice
1	20	3	6.03
2	10	6	10
3	5.32	3.685	2.01
4	20.01	3.685	4.655
5	2.66	1.34	1.33
6	5.32	0	9.31

7	6	4.69	9.975
8	14	13	12
9	16.02	6.65	7.98
10	9.975	18	11
11	10	11.305	6
12	10	14.685	8
Mean	10.77541667	7.17	7.3575
Max	20.01	18	12
Min	2.66	0	1.33
Std Dev	5.712078693	5.718535254	3.425869166

	Frustration		
Participant	Mouse & Keyboard	Touch Screen, Keyboard, Voice	Eye Track, Keyboard, Voice
1	26.7	0.665	6.7
2	2.345	2.01	0
3	3.99	15	6.6675
4	0	9	0
5	1.005	4.655	3
6	1.005	23.33331	16.02
7	1.34	0	4.02
8	4.355	4.02	4.02
9	7.315	3.35	16.02
10	24.975	21.36	0
11	4.02	11.305	0
12	13.35	17	10.68
Mean	7.533333333	9.3081925	5.593958333
Max	26.7	23.33331	16.02
Min	0	0	0
Std Dev	9.28204629	8.187134359	5.896849068

	Overall Workload		
Participant	Mouse & Keyboard	Touch Screen, Keyboard, Voice	Eye Track, Keyboard, Voice
1	81.33	37.67	82.33
2	69	60.33	50
3	52.67	58	35
4	27.67	48	33.33
5	34	62.67	31
6	41.33	67.33	74.33
7	32.67	72.33	70
8	71	64.67	63.67
9	56.33	49.67	57
10	75.33	80	70.67
11	59.67	80.67	53.33
12	59	70	55.33
Mean	55	62.61166667	56.3325
Max	81.33	80.67	82.33
Min	27.67	37.67	31
Std Dev	17.7789743	12.91067763	16.84818745

9.3 Sample QUIS Survey

QUIS 7.0

Age Group: Student Adult
Multimodal Combination: Mouse Eye Touch

PART 1: Overall User Reactions

Please circle the numbers which most appropriately reflect your impressions about using this computer system.
Not Applicable = NA.

1.1 Overall reactions to the system:	terrible wonderful 1 2 3 4 5 6 7 8 9	NA
1.2	frustrating satisfying 1 2 3 4 5 6 7 8 9	NA
1.3	dull stimulating 1 2 3 4 5 6 7 8 9	NA
1.4	difficult easy 1 2 3 4 5 6 7 8 9	NA
1.5	rigid flexible 1 2 3 4 5 6 7 8 9	NA

PART 2: Screen

2.1 Graphics on the computer screen	hard to read	easy to read	
	1 2 3 4 5 6 7 8 9		NA
2.1.1	fuzzy	sharp	
	1 2 3 4 5 6 7 8 9		NA
2.1.2	barely legible	very legible	
	1 2 3 4 5 6 7 8 9		NA

2.2.1	Screen layouts were helpful	never	always	
		1 2 3 4 5 6 7 8 9		NA
2.2.1.1	Amount of information that can be displayed on screen	inadequate	adequate	
		1 2 3 4 5 6 7 8 9		NA
2.2.1.2	Arrangement of information on screen	illogical	logical	
		1 2 3 4 5 6 7 8 9		NA

Please write your comments about the screens here:

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PART 3: Terminology and System Information

5.5	Game keeps you informed about what it is doing	never 1 2 3 4 5 6 7 8 9 always	NA
5.5. 1	Performing an operation leads to a predictable result	never 1 2 3 4 5 6 7 8 9 always	NA

Please write your comments about terminology and system information here:

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PART 4: Learning

4.1 Learning to operate the system	difficult	easy	
	1 2 3 4 5 6 7 8 9		NA
4.1.1 Getting started	difficult	easy	
	1 2 3 4 5 6 7 8 9		NA
4.1.2 Learning optimum strategy	slow	fast	
	1 2 3 4 5 6 7 8 9		NA
4.1.3 Time to learn to use the system	slow	fast	
	1 2 3 4 5 6 7 8 9		NA
4.2 Exploration of features by trial and error	discouraging	encouraging	
	1 2 3 4 5 6 7 8 9		NA
4.2.1 Exploration of features	risky	safe	
	1 2 3 4 5 6 7 8 9		NA
4.2.2 Discovering new features	difficult	easy	
	1 2 3 4 5 6 7 8 9		NA

Please write your comments about learning here:

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