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Comparing Capacitive Apples against Arrow Keys as input devices in a Game

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Short summary
Our experimental concept involved comparing two different bi-directional input methods in a Unity Game. The first input method being the traditional arrow key system, whilst the second being four apples positioned in a north, east, south, west layout. The apples acted as capacitive sensors, such that upon touching or moving close to them, a variable vector force upon the object in the game was initiated. The objective of the game was to play as a spherical orange object (game object), moving around the 3D virtual world, and to collect eleven randomly positioned cuboids on a 2D bounded plane in the shortest time possible.

Hypothesis

H1 (alternative): "Study participants will achieve a shorter time completing the objective when using arrow keys rather than capacitive apples.". This hypothesis was chosen due to our expectation that participants may find the keyboard faster to use due to the arrow keys being closer together and the reduced travel distance. We also believe that most participants will already be very familiar with the keyboard as an input device. We selected only one hypothesis as this reduces the scope of the experiment, meaning we could collect a wider sample of results in the given time. This improves the likelihood of the results tending towards significance and reduces the probability of incorrectly rejecting the null hypothesis, due to random chance giving the impression of a trend.

H0 (null): "There is no statistically significant evidence to suggest that any one input device allows for shorter completion time of the objective".

To draw a conclusion of these hypotheses, we employed various statistical tests to measure the performance of the two input devices. When examining our data using a One Tailed Paired T-Test, we will use a significance level of $< 5\%$. For the data set of each device, we calculated the highest and lowest values, the lower and upper quartiles, the interquartile range, the median and the mean. These values will be used to compare performance. These measures demonstrate the range and average of the results, whilst highlighting notable variation in maximum or minimum values, such as anomalies. Some of these measures can be presented in box and whisker plots, offering a visual representation.

Experimental design

1. Independent Variable: Input device - capacitive apples and keyboard arrow keys.
2. Dependent Variable: Time taken to collect eleven items in a simple game.
3. Control Variables:
    - The bounds of the game arena, and bounded upper movement speed.
    - Amount of cuboids to be collected.
    - The experimental brief participants were given.
    - The practice run for both input devices.
    - Future participants were not disclosed previous participants results.

The experimental setup consisted of an Arduino, four apples and a laptop running Unity 5.1. The setup was placed on a table approximately waist high. The apples were connected to the Arduino with wires that sent and measured changes in electric charge. The apples were positioned in an analogous way to the layout of a compass. The northern apple applied an upward force to the sphere, the western apple moved the sphere left, the eastern apple moved the sphere right and the southern apple moved the sphere down, in the game. Multiple apples could be activated to achieve diagonal movement e.g. north west. The apples had variable thresholds which provided different rates of acceleration based on the distance of your hand from the apple. Both devices provided an accelerating analogue input (up to a maximum capped velocity). Whilst this is not ideal for a keyboard button press, which is inherently binary, it was necessary to ensure the range of movement of the game object was consistent between input schemes. The Arduino was connected to Unity via the laptop, through serial ports. The arrow keys being used to control the game, were on the keyboard of the laptop running the game.

Each participant had instructions recited to them in an identical manner from a pre written script. The participants were then given a practice run for both input devices. The purpose of the practice run was to attempt to accommodate for the familiarity of participants with either of the input devices. The participant was given up to five minutes to practice or until they felt comfortable with both input devices.

The experiment was performed within subjects, meaning every participant had a single game round using both input devices. Every two rounds, we swapped the order of which input devices each participant started with, as a means of counterbalancing, to aid in the elimination of sequence effects caused by participants experiencing one input device before another, and thus being mentally prepared or alternatively fatigued by the previous game round, which could unfairly influence the final result. The random positioning of the cuboids helped to eliminate learning bias, by preventing the participant from performing better by remembering the previous locations of the cuboids. After all cuboids were collected, their time would be automatically saved by the game.

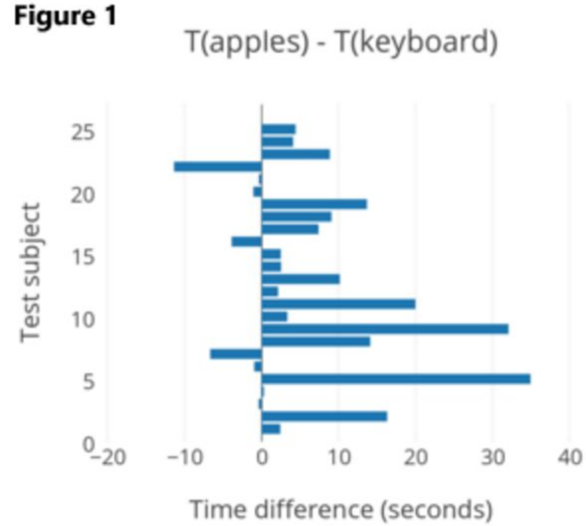
A further measure taken to eliminate bias, was the decision not to disclose any results to participants in order to prevent them from competing (a motivation factor) and distorting the consistency of the results through a systematic bias.

After running a trial experiment we discovered that the camera view was too close to the sphere, obscuring the view of the collectible cuboids which would have resulted in a comparison of a participant's search ability rather than the input devices themselves. As a result we increased the camera's field of view, revealing all of the 2D arena. We also increased the size of the cuboids as originally they were too small, requiring a frustrating amount of precision, which created fatigue - a sequence effect which may have distorted the results. The apples often were accidentally displaced by quick, sudden movements. To counter this we taped the apples to the table. The original game was a platform which involved extra features, such as being able to fall off the game platform. However after trial runs, we simplified the game so that we were testing the input devices, rather than the participants' game playing ability.

Summary of the participants

We have had a total of 25 participants, none of which had difficulty understanding the requirements. The participants were aged 18-23 and all had a Computer Science background. Given participant feedback, we believe that the actual game complexity itself had negligible impact on the results of the experiment. This acted as a further means of control. Generally participants enjoyed the experiment and found the game simple and easy to understand and the apples both novel and amusing.

Figure 1



The results

We performed a paired one tailed T-Test (because both sets of data come from the same person) on both sets of data.
The P-Value we obtained is : 1.40%

There existed a systematic error in our recorded results for the time taken when using the apples. This was measured consistently as being exactly 1.5s and after investigation we found this was caused by a serial port delay which prevented the user from being able to use the apples immediately when the game started. We have therefore deducted this time from all results before performing any statistical analysis on our data. The precision of the timer was to the nearest millisecond. Given that all our results were significantly greater than this, we have not included uncertainty calculations as part of our statistical analysis.

There also exist outlying data points which do not fit the general trend, though given that we had a small participant sample size, we decided to keep these results as we do not yet know if they are anomalous. The resulting (adjusted for systematic error) overall mean for the apples is 26.31 seconds and the mean for the keyboard arrow keys is 21.26 seconds. This shows overall, inclusive of all results the keyboards are generally shorter.

Fig 1. demonstrates that for almost all participants, a shorter time was achieved with the keyboard than the apple. This was an exception in seven of the 25 participants (almost a quarter) had faster times with the apples. Overall the trend shows that when the apple inputs were shorter they tended not to be as short as when the keyboard times were shorter relative to the other input device used.

Fig 2. Is a frequency distribution graph that displays the number of times a result occurred for each input device. The graph shows that firstly the keyboard produced faster times, secondly, that no score of < 15 seconds were achieved using the apples and finally all scores above 35 seconds were produced by using the apples. An interesting observation that can be seen is that the timings for both input devices approximately follow a normal distribution (bell curve). Error bars are not relevant in our experiment as participants didn't perform multiple runs of the game under the same input device.

Fig 3. The box and whiskers plot shows us a number of items for each data set: The range (minimum to maximum), interquartile range (lower quartile to upper quartile) and median:

	Median	Minimum	Maximum	Lower Quartile	Upper Quartile
Apple's	24.66	16.16	50.89	20.29	30.28
Keyboard	20.62	12.39	34.56	17.46	25.67

Figure 2

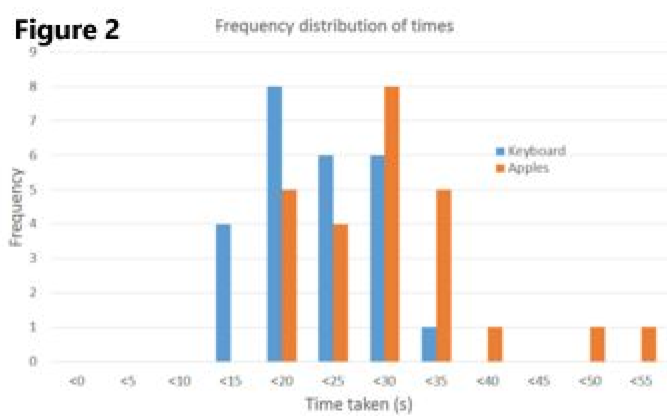
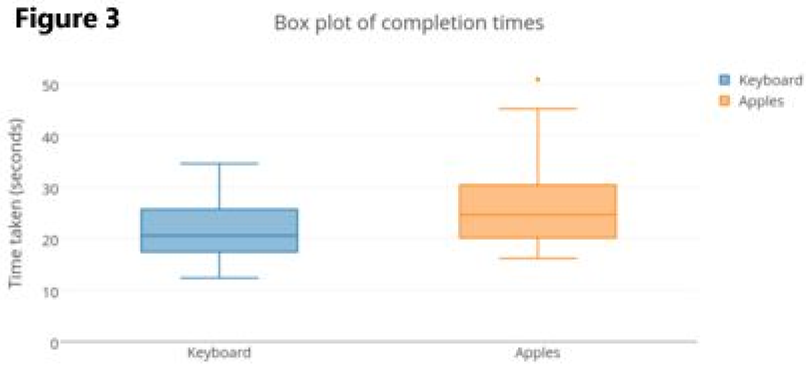


Figure 3



Conclusion

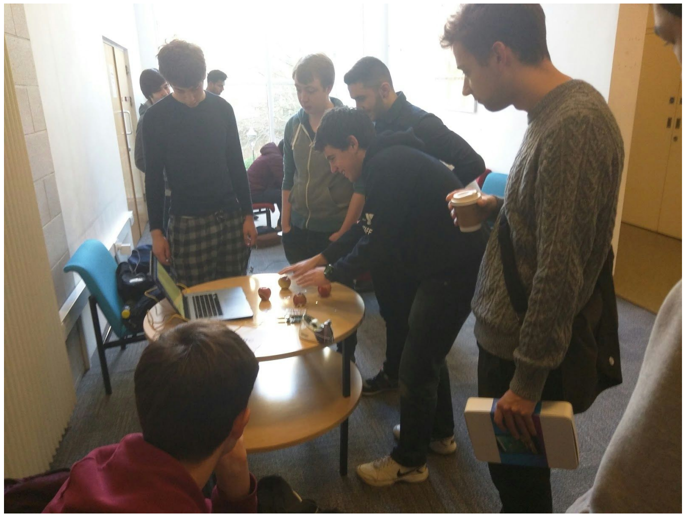
After analysing the box plot of the two sets of times (apple and keyboard times), one can observe the plot for the keyboard is more compact and all measures on the box plot are smaller. This infers that the times for the keyboard are lower than the times that were obtained by the apples. Both the range and interquartile range indicate that there was more variance in participant performance time using the apples as an input method.

After statistical analysis on the data we recorded, we have come to the conclusion that the keyboard is likely (beyond significance) to be better than the apples for controlling the game to obtain the fastest time. We came to this conclusion based on two pieces of evidence; the T-test as well as visual inspection of the graphs (specifically Fig. 1). The P-value obtained from our T-test was 1.4% which is well under the 5% significance level needed to reject the null hypothesis (H0) and accept H1.

Based on our results, we accept H1 and reject H0.

Future improvements to experiment

We do not know specifically why the keyboard input device tended to be faster than the apples. There are a number of new experiments we could perform using a similar setup, with different hypotheses. In order to perform these experiments, we would re-initialise the apparatus to create an experiment in which we start from a setup where the capacitive apples are as close in design to the keyboard arrow key setup as possible. Each new experiment would involve changing one property about this new system (i.e adjusting the spacing of the apples, difference between using one hand vs two on the apples, smaller apple pieces etc) which we could then use to quantify and reason about why one input device may be more effective than the other.



- Having greater diversity of participants e.g. different academic backgrounds, different ages and interests would allow results to be more representative of an average human.
- Increased learning time would decrease the effect of inexperience using apples in comparison to keyboard arrows. Given the demographic of our sample group, the relative experience of our sample group using keyboards may have had a bias in favour of keyboards on our experiment.
- There was a 1.5 second delay on initialisation of the apple input device, in future, we would have re-done the experiment to be sure that the delay didn't confuse participants. Practical time constraints prevented us from re doing it.
- Only one input device should be enabled at any one time to avoid interference between input devices which would prevent accidental movement and allow the user to place their hands in a more comfortable position without restriction.
- Moving the experiment to a consistent, distraction free location would have ensured a greater degree of fairness in our test, especially where other participants could not observe others performing the experiment.
- It would also be beneficial to have repeated trials per participant to give a better representation of their true ability with each input device.

Team organization - All team members contributed equally.