Evaluating Audio, Visual, and Tactile Reaction Systems

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Reaction Time, Visual, Audio, Tactile, Sensory System, Stimulus

ABSTRACT: This study investigates reaction times (RT) across audio, visual, and tactile stimuli, utilizing a custom-built Arduino device for measurement. The methodology involved collecting 100 RT measurements for each stimulus type from a single participant, comparing these with online tests and a vibration-phone-tactile test to assess variance and method reliability. Results revealed mean RTs of 190.3 ms (audio), 221.1 ms (visual), and 200.5 ms (tactile), with online and vibration-phone-tactile tests showing generally higher reaction times. The custom RT device successful use in measuring RT's highlights its promise for patient diagnostics and assessing neurological or sensory disorders. The discussion explores how different testing modalities can influence reaction time outcomes, creating the necessity for standardized protocols in RT research to ensure reliability of results.

INTRODUCTION

Reaction time (RT) is an essential metric that quantifies the speed at which an organism responds to a specific stimulus. This measurement is defined as the duration from when the stimulus is presented to the initiation of a voluntary response [1]. This process begins with the nervous system's recognition of the stimulus, followed by the transmission of neural signals to the brain, and subsequently to the motor neurons that activate the hands and fingers to respond to the stimulus. Research has established average RTs for college-aged individuals, with mean RTs being approximately 190(ms) for visual stimuli and 160(ms) for auditory stimuli [1]. Various factors that influence RT including age, sex, the hand used (left or right), central or peripheral vision, and other physiological and psychological conditions such as fatigue, fasting state, and intelligence [1]. Understanding these factors is crucial for interpreting RT experiments and their implications for human cognitive and motor function.

This research investigates human reaction speeds for three different types of sensory stimuli: tactile (touch), auditory (sound), and visual (sight). The objective is to quantitatively compare reaction times, with the hypothesis suggesting that tactile stimuli will elicit the fastest responses, auditory stimuli will result in the next fastest reaction times, and visual stimuli will provoke the slowest responses. This hypothesis stems from the premise that each sensory type utilizes different neurophysiological pathways and cognitive processing times, thereby influencing the speed of human reactions [4].

RT serves as an indicator for a range of disorders affecting processing and motor response. Impairments in visual or auditory perception, cognitive processing in conditions like Alzheimer's or motor functions as seen in Parkinson's disease, directly prolong reaction times [1]. Furthermore, attention disorders such as ADHD, and the aftermath of brain injuries or strokes also impact this timing due to disruptions in the perception-processing-action cycle [2]. This underscores the value of reaction time analysis in diagnosing and monitoring neurodegenerative diseases and cognitive disorders, highlighting its broad applicability across various medical conditions [2].

MATERIALS AND METHODS

Task and Procedure

The RT test was conducted using a custom-built device, which was assembled and programmed using an Arduino board and C++ language. As depicted in Figure 1, this apparatus was designed to evaluate reaction times across visual, audio, and tactile stimuli, utilizing a white LED, an active buzzer, and a servo motor for each type of stimulus respectively. Initially, users were greeted with an interface providing an overview of the test. Subsequently, they were prompted to choose among audio, tactile, and visual tests via selection buttons. A ten-second countdown commenced to ready the user before the start of the test, which was composed of 10 trials. In these trials, RT was measured as the interval between the onset of a randomly timed stimulus (varying between 0 to 10 seconds from the previous stimulus) and the user's response by pressing the designated button. A rising-edge signal button detection was utilized to defer attempts from the participant preemptively pressing the button before the stimulus begins. Data for individual reaction times were recorded and displayed on the serial monitor, while the average reaction time was shown on the device's LCD screen. From a single participant, a total of 100 reaction times were gathered for each of the three different sensory tests for subsequent analysis. A video demonstration of the apparatus and the code utilized for the device is presented in the Appendix below.

Online tests were used to gather additional visual and auditory reaction times, while a vibration-phone test measured tactile responses, all from the same individual. This approach aimed to standardize comparisons across the testing modes and verify the constructed reaction time test module validity.

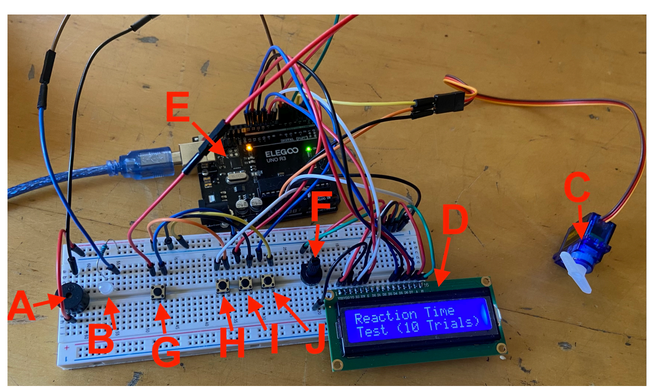

Figure 1. Arduino Setup for Reaction Time Tests for Visual, Audio, and Tactile. Key components are labeled as follows: A – Active Buzzer (audio output), B – White LED (visual stimulus), C -

Servo Motor (tactile stimulus), D - LCD Display (user interface and feedback), E - Arduino Board (central control unit), F - Potentiometer (adjustable contrast for LCD), G-J - Buttons (input devices for user responses and test selection).

Data Analysis and Comparison with Literature Values

Data from all reaction tests were converted into a .xlsx file for analysis. Utilizing Excel, any erroneous data points were deleted. A box and whisker chart was then generated to visualize the respective times (measured in ms) for visual, audio, and tactile reaction time tests, shown in Figure 3. A composite figure was generated for the reaction times, although they were not tested simultaneously.

Outliers were attempted to be removed from the data set before analysis using the 1.5*IQR (Interquartile Range) method. The IQR represents the range in which the middle 50% of data points fall and is calculated as the difference between the 75th and 25th percentiles of the data set. The lower bound for outliers was set as the 25th percentile minus 1.5 times the IQR and the upper bound was set as the 75th percentile plus 1.5 times the IQR. Data points falling below the lower bound or above the upper bound were considered outliers and were removed from the analysis.

Additionally, the gathered reaction times were compared to values from existing literature, shown in Figure 2. This comparison aimed to evaluate the changes in reaction times for visual, auditory, and tactile measurements over the past twenty years. It also intended to explore the considerable variance observed between different measurements. Furthermore, this analysis sought to confirm that the reaction times of the study's single participant were within the expected physiological range.

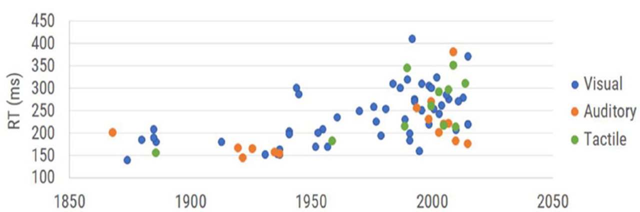

Figure 2. Historical Trends in Reaction Time Measurements. This figure presents reaction time data extracted from various studies, segmented by sensory modality (visual, auditory, and tactile) and plotted against the year of data collection. This figure was obtained from (Holden et al.) [3]

RESULTS

For each sensory type (audio, tactile, and visual) a total of 100 reaction time measurements were collected using the custom-built device. The data from these tests were then visualized using a box-and-whiskers plot to compare the distribution patterns of reaction times across the different stimuli. Contrary to initial expectations, the audio tests yielded the shortest average reaction time at 190.3 milliseconds, followed by tactile tests at 200.5 milliseconds, and visual tests also at 190.3 milliseconds. Notably, the visual reaction times exhibited the greatest variability, as indicated by the wider spread of the whiskers in the plot. Figure 3 presents this graphical representation, highlighting the differences and variance in reaction times among the tested sensory modalities.

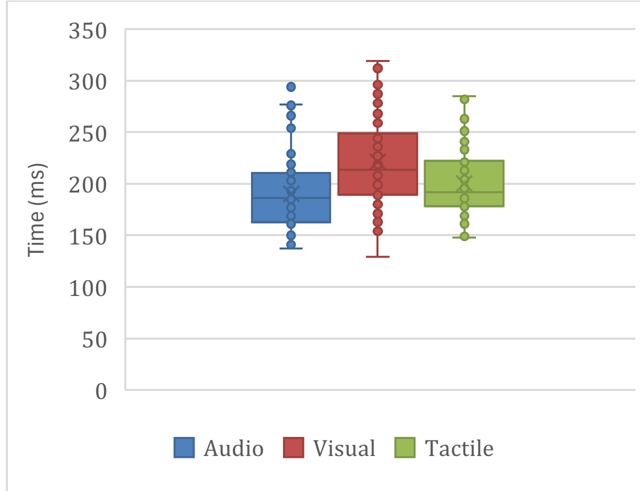

Figure 3. Box-and-Whiskers Plot of Reaction Times for Audio, Visual, and Tactile Tests. This graph compares the distribution of reaction times, measured in milliseconds (ms), across audio, visual, and tactile stimuli. The mean reaction times were 190.3 ms for audio, 221.1 ms for visual, and 200.5 ms for tactile tests. Visual tests showed the greatest variability with a standard deviation of 39.6 ms, evidenced by the length of the whiskers, indicating a wider spread of reaction times compared to audio (Std: 34.0 ms) and tactile (Std: 30.4 ms) tests.

Table 1 provides a comprehensive comparison of reaction times measured in milliseconds across various test modalities. It contrasts the mean, median, standard deviation, minimum, maximum, and range of reaction times from the study's audio, visual, and tactile tests with those obtained from online tests and a physical ruler test. The data reveal variations in reaction times between the traditional methods used in the study and alternative testing approaches, offering insights into the consistency and variability of sensory response across different testing conditions.

(ms)	**Audio**	**Visual**	**Tactile**	**Audio(O)**	**Visual(O)**	**Tactile(R)**
Mean	190.3	221.1	200.5	229.6	237.2	210.6
Median	186.0	213.5	192.0	231.0	239.5	235.2
Std	34.0	39.6	30.4	34.9	33.6	33.9
Min	137.0	129.0	148.0	157.0	206.0	180.5
Max	294.0	319.0	285.0	294.0	355.0	361.2
n	100.0	100.0	100.0	40.0	40.0	40.0
Range	157.0	190.0	137.0	137.0	149.0	180.7

Table 1. Descriptive Statistics of Reaction Times for Sensory types: Study vs. Online and Ruler Tests. This table compares reaction times, in milliseconds (ms), for audio, visual, and tactile stimuli obtained from the study with those from online tests (Audio(O), Visual(O)) and a physical ruler test (Tactile(R)). The study's results show mean reaction times of 190.3 ms for audio, 221.1 ms for visual, and 200.5 ms for tactile stimuli. Online tests yield higher mean reaction times: 229.6 ms (audio), 237.2 ms (visual), with the ruler test for tactile response at 210.6 ms. The table also details the median reaction times and standard deviations, reflecting the spread of values within each test category. Sample sizes (n) indicate the number of measurements taken.

DISCUSSION

The objective of this experiment was to evaluate the accuracy of the custom-built RT device and to compare its performance with that of existing online reaction time testing platforms. Figure 3 illustrates the distribution of reaction times for audio, visual, and tactile stimuli. The results indicate that auditory stimuli generate the quickest response, with an average reaction time of 190.3 ± 34.0 ms, followed by tactile stimuli at 200.5 ± 30.4 ms, and visual stimuli at 221.1 ± 39.6 ms. This pattern suggests that the delay between hearing the buzzer sound and pressing the button is shorter than the delay caused by the flashing LED light or the movement of the servo motor.

In evaluating the accuracy and reliability of these measurements, it's crucial to account for potential delays introduced by the electrical components of the device. Factors such as internal resistance, inherent delays in the servo mechanism, and the latency of the audio buzzer can impact the time it takes for a stimulus to be initiated. These elements could introduce a minor discrepancy between the intended start time of the stimulus and its actual execution. Further research is needed to accurately quantify these time delays for each component and to assess their significance on the overall results.

When analyzing the reaction times (RTs) from online assessments involving physical, auditory, and visual tests, an interesting pattern emerged that closely mirrored the trends observed with the custom-built RT device, shown in Table 1. The average reaction times recorded were 229.6 ± 34.9 ms for auditory stimuli, 237.2 ± 33.6 ms for visual stimuli, and 210.6 ± 33.9 ms for tactile stimuli. For the online tactile test, participants were prompted to press a button on their phone in response to a buzzing sound. The auditory and visual online tests required participants to press the spacebar in response to stimuli presented on a computer screen, either visually or through sound. Contrary to the findings from the physical device, the online tests showed that tactile reactions were the quickest, followed by auditory and then visual reactions. This variation may be attributed to the interactive mechanisms of the tests.

The slower reaction times observed in the online tests, as compared to those measured using the custom-built device, can be attributed to inherent delays associated with the complex operating systems on which these tests are run. These systems are optimized for "smooth" operation from a user experience perspective, rather than for precision and accuracy [3]. Consequently, the user interface of a computer is often designed to prioritize visual smoothness over exact timing, introducing inherent delays and variabilities in reaction time measurements that are influenced by both the computer and its operating system [3]. This trend is observed in Figure 2, as technology becomes more advanced the RTs become less accurate.

The results from the physically constructed device did not align with the initial hypothesis, which suggested that tactile responses would be the fastest, followed by auditory, and then visual responses. In contrast, the online tests supported this hypothesis, indicating that tactile responses were indeed the quickest, followed by auditory and then visual. However, it's crucial to consider the overlap in the mean reaction times and their associated uncertainties. The reaction times across different modalities were relatively close to each other, falling within the margins of error, which indicates a significant overlap in measurements.

Regarding the challenges encountered with the physical RT device, several issues were noted. The external wiring connecting the Arduino to the LCD was problematic, causing confusion and often interfering with the display's functionality. It was necessary to replace several wires to enhance the LCD's communication with the Arduino. Furthermore, the inclusion of the tactile test introduced complications. Specifically, connecting the servo motor to the 5V power supply caused an overload, resulting in the LCD flickering and turning on and off. This issue was resolved by connecting the servo motor to the separate 3V power source, which effectively mitigated the interference. Despite these obstacles, the buttons used in the device provided excellent haptic feedback, clearly indicating to participants when a successful button press had occurred.

The limitations of this study primarily arise from its reliance on the reaction times of a single individual. Ideally, a more robust sample size, such as 100 participants for each type of test, with each participant undergoing 100 trials, would provide a more accurate estimate of population statistics and enhance the reliability of the findings. While efforts were made to minimize timing errors introduced by the Arduino, the potential for unavoidable delay remains. An interesting avenue for future research could involve comparing the reaction times, or specifically the time accuracy, of different microcontrollers to identify which offers the most precise measurements.

Moreover, the variability in sample sizes across different test groups (e.g., 100 vs. 40 participants) introduces additional uncertainty in directly comparing the performance of various devices. This inconsistency complicates the task of accurately estimating the relationship between the different testing methods.

Future developments in the reaction time testing device could focus on validating and refining the device's code logic. The creation of a Printed Circuit Board (PCB) and the development of a casing through 3-D printing or CNC milling could enhance the device's functionality and durability. With an improved version of the device, a more comprehensive statistical analysis could be conducted. These tests could utilize methods such as t-tests, ANOVA, and leveraging the assumption of a normal distribution enabled by a larger sample size. This would facilitate a more informed hypothesis.

Applying the findings from this experiment could significantly contribute to the standardization of RT testing as a medical diagnostic tool. RT testing has potential applications in monitoring and diagnosing a range of conditions, including Alzheimer's disease, Parkinson's, ADHD, and other physiological disorders. Developing a biomedical device that is standardized and recognized across all medical and research fields could greatly reduce inconsistencies among RT testing modules [2]. This would create a standard framework for applying this metric to common human diagnostics.

CONCLUSION

Ultimately, it was found that there was a difference in the RTs between the audio, visual, and tactile reaction systems. Further examination is needed to establish a direct relationship between each type of reaction test and its subsequent RT. Future studies utilizing this information could guide real-world medical applications and provide insights into the role that RT plays for baseline comprehensive physical examination.

The introduction of additional RT methods or individuals into the system could have complicated the results and made it more difficult to determine the direct effect of the RT test type on reaction time. The significance of this research largely pertains to the clinical and medical application of human cognitive examination.

AUTHOR INFORMATION

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ABBREVIATIONS

RT, Reaction Time; ms, millisecond; ADHD, Attention-deficit/hyperactivity disorder; LED, Light Emitting Diode; LCD, Liquid Crystal Display; IQR, Interquartile Range; PCB, Printed Circuit Board;

AI USAGE STATEMENT

AI was used for revising, editing, and grammar checks in this paper, as well as for supporting initial research tasks. Final analysis/conclusions were made by the author without AI.

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APPENDIX

https://github.com/jogoebel/BMME375RT.git