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Accurate reaction time methods demonstrate similar results from different sensory modalities

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Over the past few decades, there has been a significant number of reports that suggested that reaction times for different sensory modalities were different – e.g., that visual reaction time was slower than tactile reaction time. A recent report by Holden and colleagues stated that (1) there has been a significant historic upward drift in reaction times reported in the literature, (2) that this drift or degradation in reaction times could be accounted for by inaccuracies in the methods used and (3) that these inaccurate methods led to inaccurate reporting of differences between visual and tactile based reaction time testing. The Holden study utilized robotics (i.e., no human factors) to test visual and tactile reaction time methods but did not assess how individuals would perform on different sensory modalities. This study utilized three different sensory modalities: visual, auditory, and tactile, to test reaction time. By changing the way in which the subjects were prompted and measuring subsequent reaction time, the impact of sensory modality could be analyzed. Reaction time testing for two sensory modalities, auditory and visual, were administered through an Arduino Uno microcontroller device, while tactile-based reaction time testing was administered with the Brain Gauge. A range of stimulus intensities was delivered for the reaction times delivered by each sensory modality. The average reaction time and reaction time variability was assessed and a trend could be identified for the reaction time measurements of each of the sensory modalities. Switching the sensory modality did not result in a difference in reaction time and it was concluded that this was due to the implementation of accurate circuitry used to deliver each test. Increasing stimulus intensity for each sensory modality resulted in faster reaction times. The results of this study confirm the findings of Holden and colleagues and contradict the results reported in countless studies that conclude that (1) reaction times are historically slower now than they were 50 years ago and (2) that there are differences in reaction times for different sensory modalities (vision, hearing, tactile). The implications of this are that utilization of accurate reaction time methods could have a significant impact on clinical outcomes and that many methods in current clinical use are basically perpetuating poor methods and wasting time and money of countless subjects or patients.

Citation

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Introduction

Current methods used to measure reaction time are inaccurate and invalidate the clinical value of the measurement. Delays and variability introduced by human interface devices (HID) such as computer mice, touchscreens, and keyboards have resulted in incorrect measurements and a consequential assumption that human reaction time has gotten slower over the past 50 years due to increased sloth and laziness [1].

Studies in the past, claiming clinically significant values, cannot be used to truly measure reaction time. There is a degree of offset in the hardware being used, resulting in values that do not make physiological sense. In a paper published by Thomson et al., baseline choice reaction time was measured to be around 500ms and could increase up to 2.5 seconds after anesthetization. Using a touchscreen as their hardware for user input, at least 200ms of offset is added to each measurement due to inaccuracy of the device [2].

Previous experimentation has been done on visual, auditory and tactile reaction times, and how other unimodal blocks would divide the attention, but only with very few test subjects [3]. A comprehensive understanding of how each modality differentiates under varying conditions is not yet established. Although it has been tested many times in the past, the experimentation has never been accomplished with appropriate hardware to accurately obtain values. There have also been tests exploring the effect of visual, auditory, and tactile stimuli on reaction time when factors such as body mass index and sex are taken into account. Accurate conclusions and concrete analysis are currently prevented by the hasty assertion that reaction time remains low in healthy subjects. Further research, including better metrics for determining health and larger breadth of individuals studied, is still needed to obtain accurate results [4].

Various studies have looked at individual types of stimuli and how intensity affects reaction time. In a sample of visually normal subjects, an experiment explored the effects of different colors of light on simple reaction time. With light, a change in wavelength directly correlates to color perceived. Certain colors like red proved to have statistically significantly lessened reaction times [5].

Tactile stimulus perception is governed by Weber’s Law, which dictates that there is a relationship between perceived stimulus and stimulus intensity [6]. Perception of tactile stimuli is directly linked to reaction time; variability of guessing combined with a subject’s perceptive threshold will determine how fast they can respond to a stimulus. This concept has been investigated accurately and experimentally confirmed through the use of the Brain Gauge.

Reaction time due to auditory stimuli has not been explored as thoroughly. Small class projects have been performed to test the impact of frequency or amplitude on the reaction time of an individual. Some, such as the one performed by students at the University of Wisconsin Madison, have hinted that auditory reaction time does not change with frequency [7]. A more exhaustive preliminary study on how the amplitude of auditory stimuli would affect reaction time will be conducted in this paper.

Methods

The reaction time collection device used to administer auditory and visual stimuli was created using an Arduino microcontroller board along with components from the ELEGOO UNO R3 Super Starter Project Kit, a commonly available toy from used to introduce children and young adults to embedded systems. It does, however, have timing accuracy much lower than 1 ms, far better than typical commodity-grade computer HIDs. The visual stimuli are delivered by a single blue LED (467 nm) for 5 trials at three different intensity levels. Using a 220Ω resistor, intensity levels were set at the lowest, middle, and highest values (based on the numerical value within the analog range assigned in the Arduino script). The auditory stimuli are given by the output from the 5V active buzzer. The pitch was set at a middle C, or C4 at 261.63 Hz, for three trials at varying intensity levels of 55, 67, and 88 decibels measured at 10 cm from the buzzer. The tactile stimuli were administered using the Brain Gauge device and custom battery with varying intensities of 25, 50, 100, 200, 300, and 400 microns displacement peak to peak. The Brain Gauge device and associated battery were developed by Cortical Metrics.

Before taking the tests, each patient was tasked with filling out a survey with questions regarding age, sex, dominant handedness, and hours of sleep the night before. Then, each subject was required to sit with their eyes closed in an upright position for one minute as a way to standardize starting physiological conditions (regulated breathing, normal heart rate, etc.). To negate as much of a learning effect as possible, subjects were thoroughly informed of the experimental procedure they would be going through, along with an explanation of what to expect with each test. The order that the different modalities of stimuli were administered was randomized for each patient using a random number generation function on MATLAB. Further, the order of intensity within each stimulus was also randomized.

Each subject took all 3 sets of tests in one sitting, positioned in a comfortable upright position in a quiet environment. The testing equipment was set on a solid, flat, and uniformly colored surface. The tactile stimuli test was given using the Brain Gauge and the connected laptop. The visual and auditory tests were given using the assembled Arduino microcontroller device and the attached laptop. Results were compiled from the 3 different sets of tests and arranged appropriately in an Excel spreadsheet for analysis. On average, each subject took approximately 15 minutes to complete all required testing and data collection, including instructional and transition periods.

Results

Four subjects were analyzed for all three stimulus modalities. Graphical representations of their various reaction times are shown below. The x-axis of the graphs indicates the intensity of the stimulus, with the intensity increasing to the right. The y-axis of the graphs depicts the corresponding reaction time at each stimuli intensity.

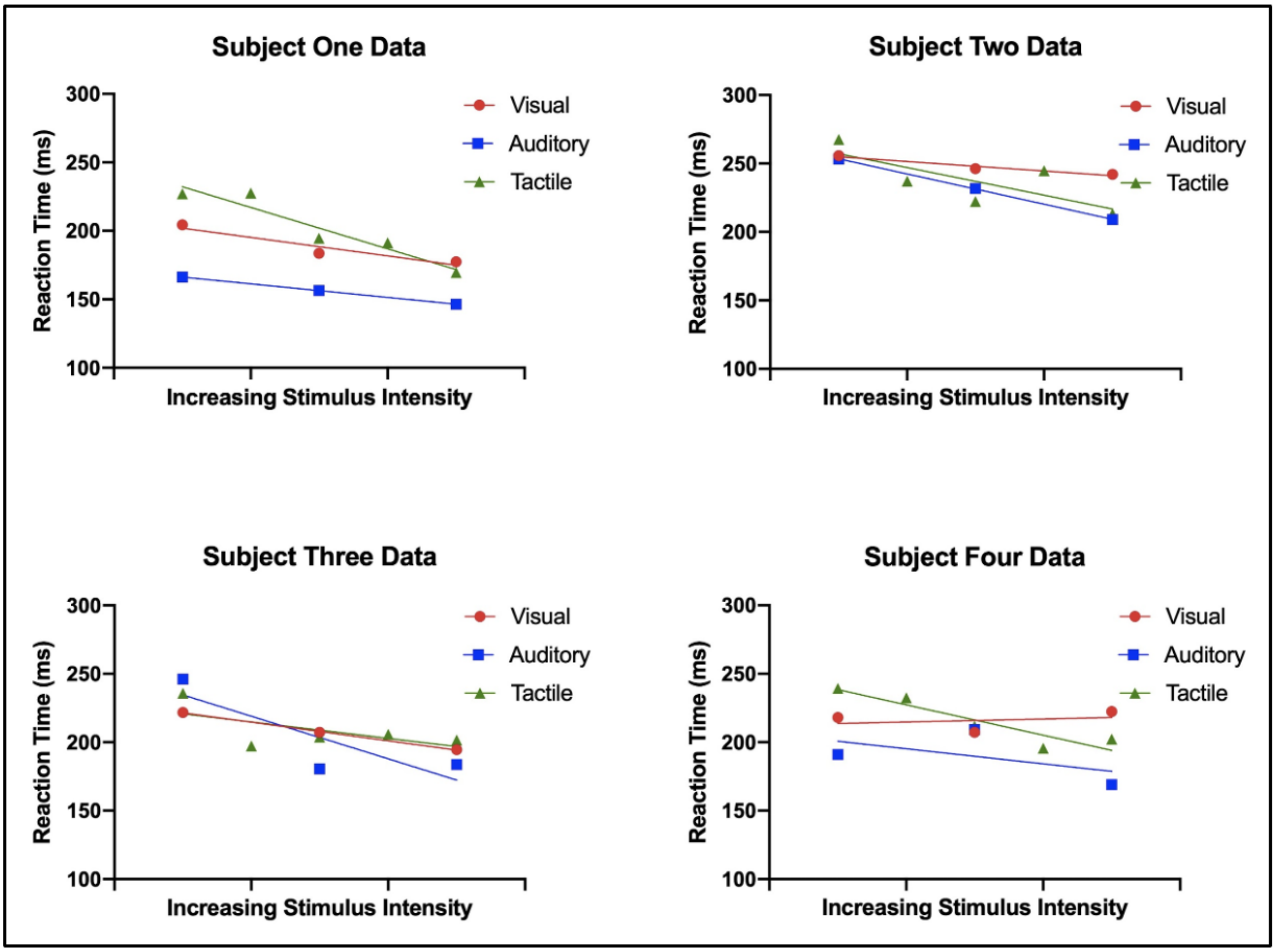

Figure 1. *Reaction Time versus stimulus intensity. With each of the stimulus modalities shown in different colors, the changing reaction time values are shown above.*

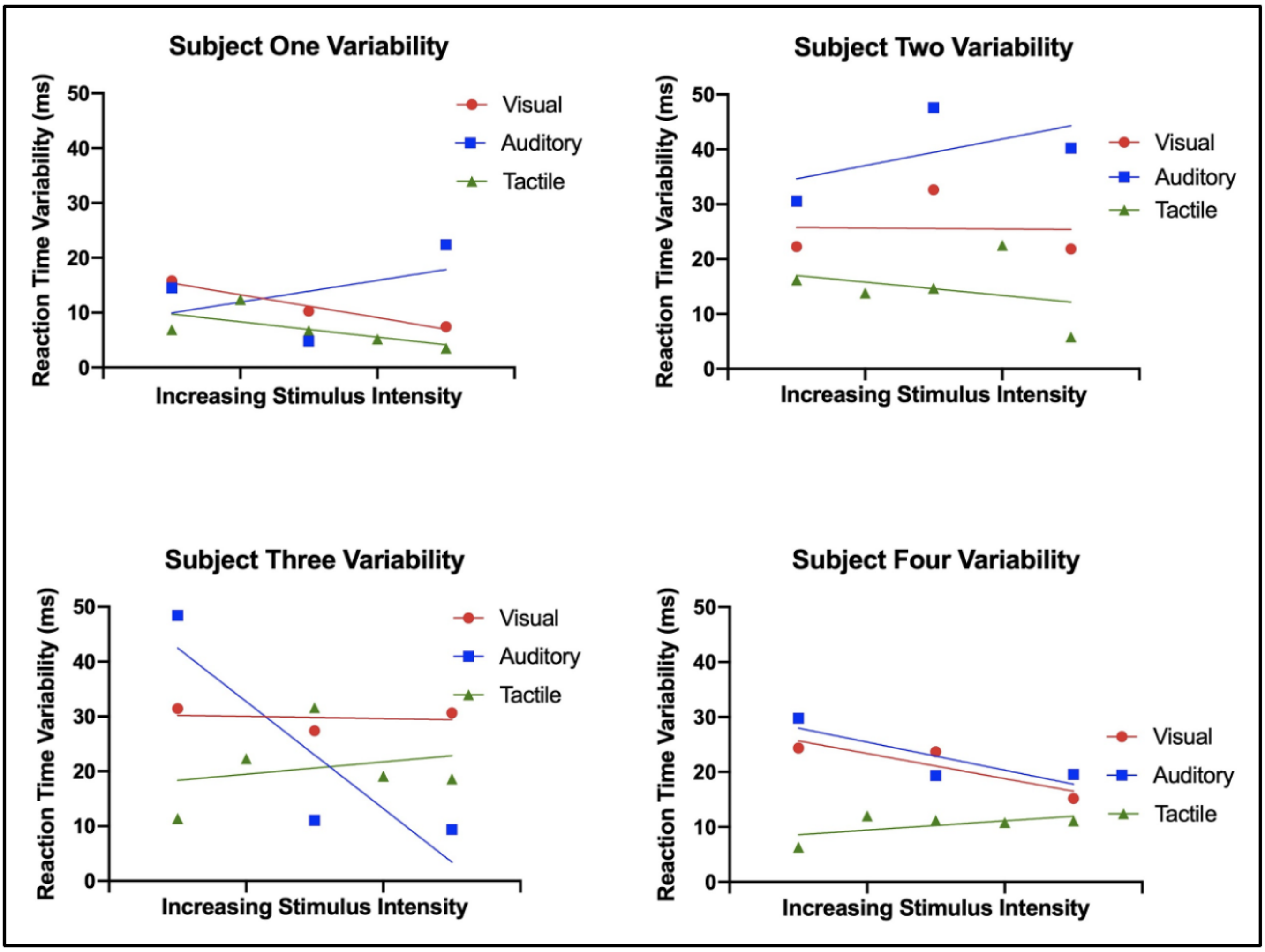

Figure 2. *Reaction Time Variability versus stimulus intensity. With each of the stimulus modalities shown in different colors, the changing reaction time variabilities are shown above.*

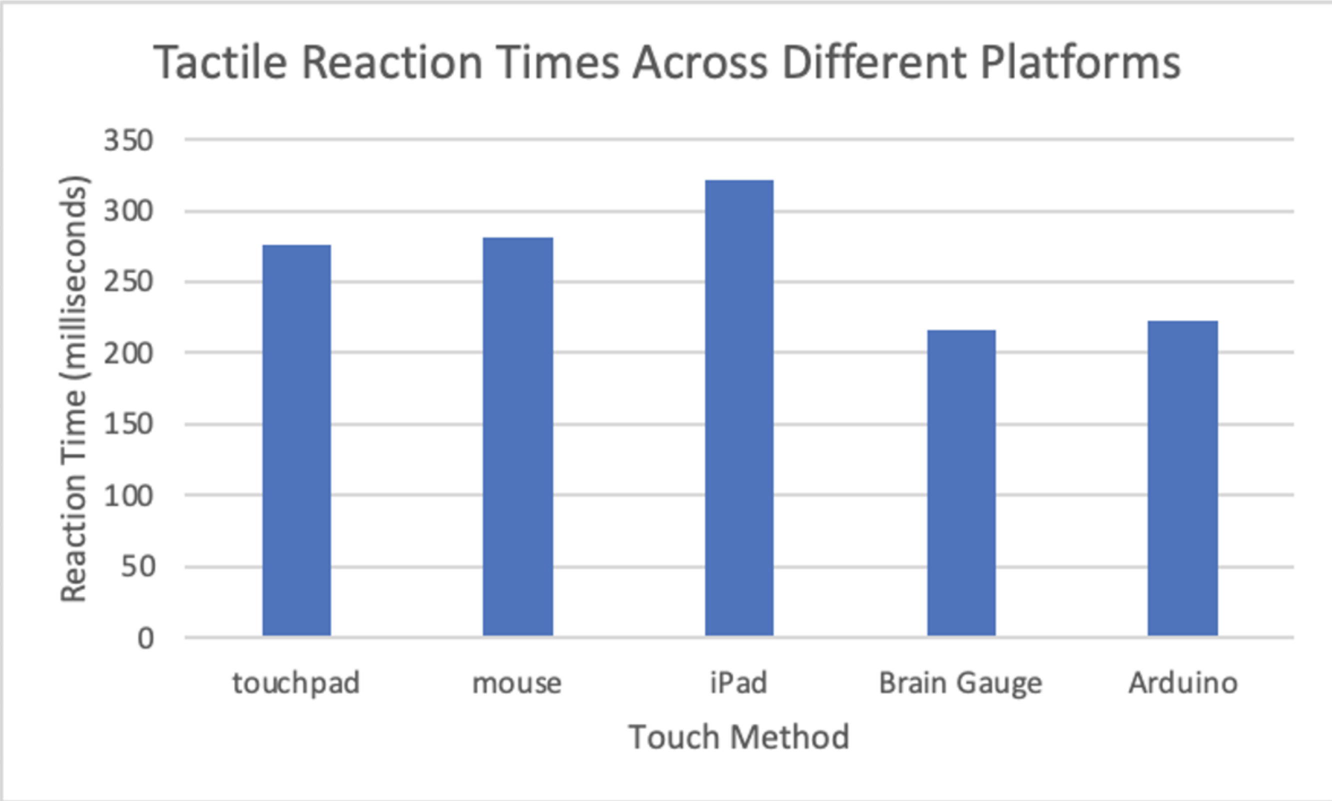

Figure 3. *Average reaction times taken across different testing platforms. Five sets of tests were done using a laptop touchpad, an external mouse, an iPad, the Brain Gauge, and our Arduino RT measurement device.*

Discussion

The data presented contradicts much of the literature from the past 150 years related to the assertions about various aspects of reaction time in healthy adults. Healthy adult reaction times have not increased, and there is no significant difference in reaction time for various sensory modalities. This statement is supported by the data collected and presented in the figures above. It can be assumed that current literature assertions of increased reaction times and differing results across stimulus modalities (i.e. tactile, visual, and auditory) can be attributed to inaccurate reaction time measurement methods.

As seen in Figure 1, all three stimulus modalities are much closer to 200 milliseconds, on average. This is significantly less than common reported figures of 275-400 ms throughout a majority of literature [1]. While there is no significant difference in reaction time across the different modalities, our data suggest that auditory reaction time may be slightly faster on average than the times recorded from tactile or visual stimuli by approximately 25 ± 10 ms. All four subjects in Figure 1 showed faster reaction time as stimuli intensity increased, which is to be expected from the literature, and therefore is probably one accurate finding in an otherwise deeply flawed literature that has remained generally accepted. It is all the more significant that a trend is seen across stimulus intensity due to the fact that the intensities were administered in random order. Subjects 3 and 4 both were given the higher intensity auditory and visual stimuli first, and they still performed faster on average than with the low intensity stimuli.

Figure 2 shows reaction time variability data for all four patients, but no consistent trends can be identified. This is in part due to the low number of test trials for each modality at each intensity level, since only five were taken at each. Future testing would include more subjects taking an increased number of measurements at each intensity level. Trial numbers were kept low to avoid a learning effect, but the range of variation was more detrimental than helpful. It would also be useful to have more data points so that the fastest and slowest reaction time values could be eliminated, as in the case of the Brain Gauge.

Figure 3 shows the disparity in reaction time measurement accuracy between common tests found online versus professional tools like the Brain Gauge and microcontroller device. Measurements taken using the laptop touchpad and the externally connected mouse were almost identical, resulting in an average reaction time of 273 milliseconds. The same test taken using an iPad gave even worse results, reporting an average reaction time value of 319 milliseconds. The Brain Gauge and Arduino devices gave very similar results, reporting average reaction time values much closer to the clinically reasonable times of 210 and 218 milliseconds, respectively. This preliminary data shows the blatant discrepancy between widely employed modern reaction time testing devices, which are slowed with delays, processing times, and touch interface calibration, and simple devices like the Arduino, which are ostensibly much more simplistic, but in their simplicity they are known to measurably produce far more accurate results.

This experiment, while simple, has increasingly serious implications moving forward. By recognizing that reaction time testing has been carried out and reported inaccurately for several decades, we can revolutionize how we clinically examine cognitive function moving forward. Reaction time is often one of the first methods used to diagnose concussions or various levels of brain trauma. If current testing methods and techniques are both unstandardized and inaccurate, there is no true way to draw accurate conclusions about a patient’s condition. Brain and neurological research is an ever-expanding field. Reaction time is one of the most studied and primitive functions of the human body, as it directly dictates how we operate on a day to day basis. A universally accepted advancement in accurate reaction time measurements has widespread implications. This valuable clinical data could be applied to everything from automated motor vehicle technology to chronic traumatic encephalopathy (CTE) research within the National Football League. Continuing to abide by outdated and demonstrably flawed data is detrimental to professionals across all fields, as well as to our general understanding of neurological and nervous system development, health, and injury.

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