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Summary

Timing Issues Encountered in Stimulus Presentation and Reaction Time Measurement While Designing Computer Based Behavioral Experiments in Cognitive Psychology

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Most of the experiments conducted in the contemporary field of cognitive psychology are designed in a computerized environment. One essential issue that should be observed while preparing computer based experiments is that, these experiments must be capable of measuring time properly because some procedures such as recording reaction time, presenting short-duration stimulus and displaying animated objects necessitate both millisecond precision timing and accurate time measurement (see Plant, 2016; Plant & Quinlan, 2013, for a discussion). Consequently, issues regarding accurate timing are addressed frequently both in research methods and instrumentation literature. The purpose of this paper is to review studies concerning timing accuracy and provide researchers with the summary of recommended solutions in the literature for several timing problems.

The Effect of Multitasking Environment on Timing Accuracy

A number of studies emphasized that Windows operating system's multitasking environment constrains accurate time measurement in experiments (e.g. Myors, 1998, Myors, 1999). Consistently, several other studies found that MS–DOS (which is not a multitasking operating system) allows precise timing (Bovens & Brysbaert, 1990; Graves & Bradley, 1987; Graves & Bradley, 1988; Segalowitz, 1987; Warner & Martin, 1999).

Although the advantage on timing accuracy provided by MS–DOS like operating systems' plain environment is apparent, it must be taken into consideration that, computerized experiments running on Windows or any other multitasking environment may have accurate timing for stimulus presentation and reaction time measurement under proper circumstances (Chambers & Brown, 2003; Finney, 2001; Forster & Forster, 2003; Plant, Hammond & Whitehouse, 2003; Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). In the recommendations section of this paper, the conditions under which multitasking operating systems provide accurate timing are discussed.

The Effect of Different Input Devices on Timing Accuracy

Keyboard and Mouse

Plant et al. (2003) tested several mouse devices both in hardware level (independent of operating system) and in Windows environment by running a reaction time experiment. They compared different brands and ports (PS/2, USB and serial). Plant et al.'s measurements indicated that, under proper conditions, the contribution of Windows to mouse response delay is negligible. However, results of response delay that is independent of operating system caused by mouse devices revealed that, there is large variability between different brands, different ports and different models of the same brand. This deviation ranged from 6.55 to 61.60 msec. Plant et al. emphasized that, it is not easy to recommend a particular brand and port for timing accuracy and they suggested that using response boxes in time critical experiments may be an appropriate choice.

Studies indicated that, like mouse devices, computer keyboards cause a substantial amount of time delay and variability of this delay among different keyboards is quite large. For example, a PS/2 keyboard tested by Plant et al. (2003) has 28.25 msec mean delay. Additionally, Neath, Earle, Hallett and Surprenant (2011) reported, one of two tested USB keyboards has 39.46 msec and the other one has 19.69 msec mean delay.

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Although several studies emphasized that mouse devices and keyboards are not proper for measuring reaction time (e.g. Li, Liang, Kleiner & Lu, 2010, Stewart, 2006) because they have substantial amount of time delay, it is suggested that these input devices may be used to collect reaction time data under appropriate conditions (Beringer, 1992; Graves & Bradley, 1987). In the recommendations section of this paper, the conditions under which keyboard and mouse may be used to measure reaction time are summarized.

Response Boxes

It may be suggested that, response boxes are the best choice to measure reaction time in behavioral experiments because they contain an internal timer. By means of the internal timer, reaction time measurement is not affected by the delay that occurs while transmitting the signal to computer (e.g. Li et al., 2010).

Parallel Port Devices

The second best choice after response boxes is using parallel port devices. Unlike USB, PS/2 and serial ports, there is no considerable delay while transmitting signals to computer through parallel port. For this reason, even if it does not have an internal timer, a simple device connected to parallel port can measure reaction time with reasonable accuracy (e.g. Steward, 2006; Voss, Leonhart & Stahl, 2007).

Game port Devices

The game port devices also appear as one of the second best choices after the response boxes. Devices connected to the game port, such as joysticks, cause little amount of delay while measuring reaction time (Graves & Bradley, 1987).

Measuring Timing Accuracy

It is recommended that, regardless of which technique is used to achieve accurate timing while running a computer based experiment, researchers must measure their experiment's timing accuracy using an external setting (e.g. Plant, 2016; Plant & Quinlan, 2013).

As opposed to the popular belief, measuring timing accuracy with the assistance of an external mechanism is a low cost and easy option in most cases. For example De ClercQ, Crombez, Buysse and Roeyers (2003) described a simple mechanism, which consists of only two computers and a photocell and it could be used to measure the computer's timing accuracy for both reaction time measurement and stimulus presentation. Smyth, Cardy and Purcell (2017) also demonstrated a plain setting in which only an ordinary digital camera was used in addition to the experiment computer. In this setting, a video of stimulus presentation was recorded in 320 fps and the video was analyzed to evaluate timing accuracy of stimulus duration.

Although such external settings are simple and low cost solutions, developing/using such mechanisms requires some amount of expertise in programming. For researchers who do not have programming experience, commercial devices, which measure timing accuracy is a viable option for evaluating timing accuracy (e.g. Plant, Hammond & Turner, 2004).

Recommendations for Increasing Timing Accuracy

In the light of above mentioned literature that considers issues regarding timing accuracy, a solution list is recommended for researchers to ensure timing accuracy in computer based experiments.

Recommendations for Optimizing Experiment Computer to Increase Timing Accuracy

Although it is difficult to provide accurate timing in experiments running on modern multitasking operating systems, it is possible to design experiments with satisfactory level of timing accuracy under appropriate conditions (Chambers & Brown, 2003; Forster & Forster, 2003; Stevens et al., 2006). Note that while they are being tested for timing accuracy, computers are configured differently than general purpose ones with the aim of decreasing timing error. Typically, those computers have no antivirus software (Garaizar & Vadillo, 2014; Neath et al., 2011), their soundcard is removed if not necessary (Plant, Hammond & Whitehouse, 2002), unneeded services are disabled (Neath et al., 2011), network connections are disabled (Garaizar & Vadillo, 2014), network card is removed (Plant et al., 2002; Plant et al., 2003), scheduled tasks are disabled and only the necessary software applications are installed (Plant et al., 2003). Additionally, the priority of the experiment program in the multitasking operating system is maximized (Chambers & Brown, 2003). From this point of view, researchers who wish to run time critical experiments should take such precautions, namely, they should consider avoiding any action that would bring extra load to the experiment computer.

Recommendations for Measuring Reaction Time Accurately by Using Standard Input Devices

Undoubtedly, most accurate devices for measuring reaction time are response boxes as they have an internal timer. For this reason, response boxes must be the first choice. Second choice may be a properly programmed parallel port device. However, in some circumstances, it is not practical to use a response box or a parallel port device. For example, in situations where a number of computers must be used simultaneously to collect data, it may be costly to acquire multiple response boxes. On the other hand, even if parallel port devices are cost-efficient, the researcher may not have enough programming and electronics knowledge to develop such tools.

Because of these, mouse devices and keyboards may be used in some conditions to collect reaction time data.

As mentioned earlier, the amount of delay caused by mouse or keyboard has a great variation across brands, port types and even different models of the same brand (Plant et al., 2003). On the other hand, the standard deviation of the delay of a particular mouse or keyboard is negligible (e. g. Graves & Bradley, 1987; Neath et al., 2011; Segalowitz & Graves, 1990). This characteristic of mouse devices and keyboards makes them viable for reaction time experiments.

Note that measuring relative response latency among different experimental conditions rather than measuring absolute latency is important in psychology experiments (e.g. Neath et al., 2011). If measuring relative latency is in question for an experimenter, the only thing to be done in the study is to balance different conditions across different experiment computers (thereby different keyboards or mouse devices).

However, if researchers are interested in measuring absolute reaction time, reaction time data must be corrected by taking account of timing delay caused by each keyboard or mouse. A practical correction may be simply subtracting the input device's mean delay from collected response latency (Graves & Bradley, 1987). To be able to do this correction, each input device's delay must be tested prior to experimentation (Beringer, 1992). However it is not very easy to perform such a test as it necessitates an external setup. For this reason, researchers may prefer to use commercial devices to test the mouse's or keyboard's delay.

Lastly, one of the critical points that must be considered by researchers is that, mouse devices and keyboards are not suitable for registering reaction time for repetitive key strokes which have very short inter-response interval (Beringer, 1992; Segalowitz & Graves, 1990). If reaction time will be registered for very fast responses, game port devices may be used because the refractory period they need before registering the following action is very short (Segalowitz & Graves, 1990).

Recommendations for Web Experiments

As in the case of laboratory experiments, accurate timing is essential for Web based experiments because in some circumstances the reaction time measurement and short duration stimulus presentation are performed in online studies.

Different from laboratory experiments, achieving accurate timing in online studies is much more difficult because the experiments are run on participants' computers that have different operating systems, browsers and hardware combinations (for discussion see Garaizar, Vadillo, & López-de-Ipiña, 2014; Schmidt, 2001).

Schmidt (2001) suggested that, researchers must run several versions of their experiment program that is optimized for a particular browser and analyze the data that was only collected from the tested browser-hardware-operating system combinations to reduce the time delay variability across participant computers.