A technical note on the precise timing of behavioral events in economic experiments

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Abstract

The increasing use of physiological recordings in experimental economics requires a precise timing of interesting events, such as the presentation of a set of choices, the decision-making moment and the reception of feedback through the display of a decision outcome. In this note we provide a simple, accurate and inexpensive solution based on the use of external photo-sensors that detect changes in light intensity on the participants' screens occurring in synchrony with experimental events. This system ensures an accurate communication between standard programs broadly used to run behavioral economic experiments, such as z-Tree, and eye-tracking devices or biosignal acquisition systems recording physiological variables, such as skin conductance, heart rate and electroencephalogram. An example is briefly discussed, offering specific guidelines for the application of this methodology in economic contexts with strategic interaction.

Keywords: Economic experiments, timing of events, psychophysiology, physioeconomics, eye tracking.

JEL codes: C90, C99, C88, B41.

1. Background

Human Skin Conductance (SC), Heart Rate (HR) and Electroencephalographic (EEG) responses have been used for almost a century as an objective measure of the manifestation of psychophysiological reactions to controlled external stimuli. The increasing rate at which Behavioral Economics integrate the use of physiological measurements to improve our understanding of economic decision-making calls for a refinement of the discipline's experimental methods. At the same time, economic experiments in strategic contexts where many subjects situated in the same room make decisions at times that depend on their continuous interaction, pose a new challenge for physiologists, as traditional physiological recording tools and methods are designed for individual experiments under more strictly controlled laboratory conditions.

The study by Bechara et al. (1997) is still one of the most prominent examples of physiological measurement of emotions through SC responses during individual decision-making in economic contexts. Later, the literature shifted to the study of physiological reactions to decision making in strategic contexts. For example, Censolo et al. (2011) studied electromyographic activity of hand muscles in a motor coordination game, while Coricelli et al. (2010) recorded SC responses in a tax evasion context. However, until recently, experimental economics has received ready-to-use solutions from the standard physiological measurement techniques adopted by psychologists to record responses of a single subject interacting with a computer interface. Lately, it has been realized that in strategic and, thus, interactive and interpersonal decision-making contexts, the exact timing of the various stimuli to which experimental subjects are exposed and the responses they provide, requires an entirely different methodological approach. For example, when the z-Tree (Fischbacher, 2007) toolbox is used, an external C system calls for timing functions that are useful for the time localization of behavioral events. However, limitations due to network-related contingencies (heavy traffic of information due to complex feedback, electricity network-induced variations in time precision, etc.) can generate time measurement imprecisions, which are critical for the validity of measurements of physiological responses evoked by a given event. Importantly, the greater the number of subjects interacting in a given experimental context, the more these timing problems are amplified.

2. The timing problem

A serious issue in this emerging collaboration between Behavioral Economics and psycohysiology is the communication of the precise timing of experimental events to the biosignal acquisition device so that these events are recorded in synchrony with physiological waveforms. Especially HR and EEG data are studied on the millisecond time scale, which means that even small timing errors may lead to a failure in detecting an otherwise present experimental effect.

Traditionally, timing information in economic experiments is provided by the presentation software that keeps internal timestamps for all events of interest. The z-Tree toolbox offers the possibility of running a C code on execution time. C has a simple function that provides the exact moment in which a subject is exposed to a specific event with a high temporal precision. However, in the case of continuous physiological measurements we need a higher precision, which should be independent of technical contingencies like traffic on the network, electric energy fluctuations, etc.

It is important to note that this is not a caveat of z-Tree, but rather of the supporting infrastructures and network resources. To be more specific, recall that a local network is usually composed by efficiency-oriented PCs, which are available in the market for a broad spectrum of users. This implies that each machine does not perform its tasks at the shortest time possible and does not guarantee a minimum delivery time, because the processor is using its resources to deal with different process threads simultaneously. Thus, a single system will appear to need more or less time to perform the same task, depending on the load of the tasks performed by the user or other users on the system (inherent processes of the operating system; Oliver et al., 1998). Therefore, depending on the system's charge, we can obtain variations exceeding the maximum allowed for the determination of the precise time in which an event occurs.

Another issue is that there is no easy and accurate way to communicate the timing of events recorded internally by the presentation software to the biosignal acquisition device. This communication between the presentation software and the signal acquisition system is standard procedure in psychophysiological experiments and is accomplished by having the presentation software send an electric pulse to the acquisition system every time it presents a stimulus or records a subject's response. This pulse is usually transmitted through the parallel port of the computer where the presentation software runs and produces a visual mark on the biosignal acquisition software. Although extensively used in psychophysiological laboratories, this methodology is still not exempt from error since in many cases the pulses sent by the presentation software do not accurately reflect the true event times due to the processing latency in the presentation computer or the speed of the communication between the two computers.

3. The use of external sensors

A finer method for recording the timing of events of interest in physiological experiments is to use external sensors. Since most behavioral events can be associated to the presentation of information on a screen or by the pressing of a button by the subject, it is possible to modify the presentation software so that each of these events results in a change of light intensity at a specific area of the subject's screen. This change can then be detected by a photosensor and transferred directly to the biosignal acquisition system bypassing timing errors associated to internal computer processing and communication lags between computers. A system using external photosensors for the detection of stimulus presentation events was described in Henelius et al., 2012. Here we present a significant extension of this methodology to accommodate the needs of economic experiments with the participation of multiple subjects interacting in strategic contexts.

The synchronization methodology we describe in detail bellow was implemented in an Etherner laboratory with a TCP/IP protocol, which guarantees the reception of information and good statistical performance, but does not ensure fixed values for the timing delivery of packages. Communication blocks beyond the experimenter's control, can lead to network saturation and even the destruction of packages which may be re-sent, but whose reception time will not be deterministic in any way.

Our proposed system detects changes from black to grey in a small square area ("plotbox") on the standard z-Tree "Active screens", which are then transmitted to the biosignal acquisition equipment. The experimentalist will only have to create a small area on the presentation screens of the z-Tree[1] or other program used to deliver the experiment. The square area becomes black on every second screen as the experiment moves along subsequent decision-making and message/feedback reception stages of the session. A photodiode, and specifically a light-dependent resistor (LDR), should be oriented towards each subject's screen, focusing on the black/white alternating area to detect the changes from black to white and vice-versa. It is recommended that a capsule is used around the

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[1] Choosing the option "New plot box" from the "New box" option of the "Treatment" menu. The black color, which achieves the maximal light difference from the default grey z-Tree screen, is obtained from the "Fill color" button of the "Plot box" pop-up menu.

sensor to isolate from environmental light variations and noise that can affect the sensitivity of light detection. In our implementation, photodiodes were encapsulated in black tape, allowing only the light from the screen area covered by the photosensor to reach the photodiode. When it detects the grey color, the LDR's resistance drops to the minimum, whereas when it detects black its resistance rises to the maximum, creating electric pulses. There are several LDR devices in the market (prices start from 0.40€) with varying ranges of lux and voltage. The electric pulses are transmitted to the biosignal acquisition equipment's[2] digital input channels, designed specifically for this function. Figure 1 depicts an example of the circuit used in this application.

The circuit will always have the same width and its delay times will not be affected by uncontrolled factors stemming from the laboratory network. Thus, knowing the length of the conductor and the parameters of the photodiode, we can identify the precise moment in which a given behavioral event took place during the experiment, using the precision data provided by the producer of the photodiode. In our case, the typical delay time of the system was precisely 35ms.

Note that this protocol is especially useful for experimental economics labs, using servers that are not destined to real time execution. Therefore, the proposed system does not depend on the type of equipment installed in any particular lab and is very robust to improvements or structural changes in the informatics infrastructure.

4. An example

In this section we describe the implementation of our synchronization protocol in a study on the physiological underpinnings of antisocial behavior (Jaber-López, T. et al., 2014). In this experimental setting, two firms bid, posting levels of quality and bribes to an auctioneer. The auctioneer then, observing the quality-bribe bids decides on the winner of the auction. In the second treatment of the experiment, the loser of the auction may "blow the whistle" to trigger a transparent revelation of the terms under which the auction was resolved. If a bribe is uncovered, the corrupt firms lose all their money. The decision of the loosing firm whether to blow the whistle, takes place after the announcement of the auction winner.

Figure 2 shows the data obtained by the biosignal acquisition software during the execution of the experiment. Panel A represents skin conductance changes (measured in microsiemens) of a participant playing as one of the two "firms". Panel B shows changes in voltage registered by the

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[2] In this application we used an MP150 Data Acquisition system by Biopac, Inc. that comes with 16 digital input entries, allowing for the simultaneous recording of timing data from 16 subjects.

photodiode attached to this participant's screen. While the participant is waiting for the decision screen to appear, the photodiode is pointing to the black square at the top corner of the waiting screen and thus registers a value of zero Volts. In contrast, the photodiode square at the top of the decision screen, which is asking the firm to make a quality-bribe bid, is white. Therefore, when this screen appears at the participant's monitor, the photodiode registers an abrupt change from zero to 5 Volts (indicated by the red arrow pointing at "decision screen onset"). The firm chooses one of the available quality-bribe bids by pressing a button that registers the bid and also changes the active screen to one with a black photodiode square. The photodiode then transmits a value of zero Volts that indicates the offset of the decision screen and the recording of the behavioral response (indicated by another red arrow pointing at "decision screen offset"). We now move to panel C where we monitor skin conductance changes of a second participant playing as the "auctioneer". A relatively low skin conductance activity is observed until approximately 810 seconds have elapsed from the beginning of the experimental session. In panel D we observe that approximately one second before, the auctioneer's screen changed from a waiting screen to the screen presenting the bids of the two firms. We can therefore infer that the rise in skin conductance observed in panel C is related to the reception of the firms' bids and to the decision making process that ensues. This process is finalized when the auctioneer registers a decision by pressing a button that also changes the color of the photodiode square from white to black. Thus, the subsequent drop of photodiode voltage from five to zero Volts marks the precise moment of the behavioral response (designated as "decision registered" in panel D). Finally, going back to panel B, we note that at the exact moment the auctioneer makes a decision, the feedback screen appears on the firm's monitor. A couple of seconds later we observe a second marked response in the firm's skin conductance panel that we can safely associate with the reception of the auctioneer's decision. In summary, after compensating for the known delay of the photosensors (35ms in our case), our system allows us to obtain a precise timing of experimental events that can be associated with the participants' ongoing physiological activity.

Legend for Figure 2:

Figure 2: Synchronous recording of physiological activity and behavioral responses by multiple participants. Panels A and C illustrate changes in ongoing skin conductance activity of two participants interacting in a strategic decision making experiment. Panels B and D depict experimental events —onset of decision making processes, reception of feedback information or

registering of behavioral responses— marked by changes in the active screens on the participants' monitors. Please see the main manuscript for details.

In table 1, we present the reaction times of firms deciding to bribe or not to bribe for the two experimental treatments (no whistle-blow vs. whistle-blow). We compare the results obtained with two different time measurement methods: a) using z-Tree's *gettime* function, and b) using the external photosensors.

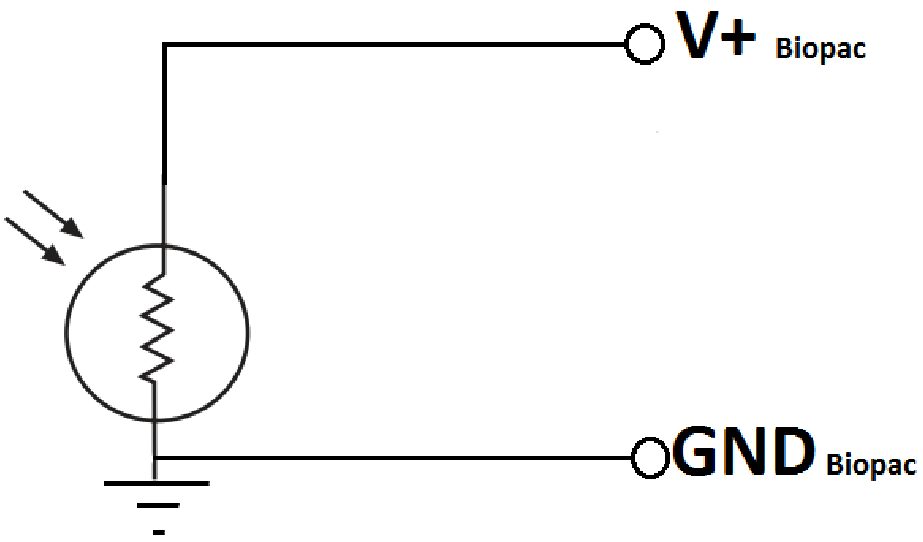

Figure 1: Circuit used in the application. GND, V+: Respectively, ground and positive signals for the biosignal acquisition equipment (Biopac) analog channel.

The comparison of the two time measurement methods across treatments and reaction times across strategies shows that:

1. The photosensors register systematically and significantly lower average reaction times than those registered with *gettime* in all cases.

In fact, the average difference of approximately 0.5 seconds is certainly significant, especially for skin conductance and other physiological measurements. However, in the example used here, we find that the loss in time precision would not lead to a wrong evaluation of the differences in response times across treatments and subject's adopted strategies. Thus:

2. Both time measurement methods would lead to similar behavioral results. Namely, not to bribe under the threat of being recovered and punished is the easiest decision to make.

Therefore, our example shows how the photosensor method registers lower and by definition more precise time measurements, but the loss in precision may not lead to different conclusions in terms of the time taken to respond and, thus, the conflict entailed in each decision.

5. Discussion

Without neglecting less costly and technically demanding substitutes of SC and HR responses like reaction times (Rubinstein, 2007) and self-reported emotions (Coricelli, 2013), the use of physiological measurements in economic contexts will increasingly provide a field of intersection between economics and psychology, letting economists empirically test conjectures concerning feelings and ethical dilemmas. In addition, the integration of eye-tracking technologies in behavioural economics can help elucidate the complex interplay between attention, motivation and economic decision making (Reutskaja, 2011).

The protocol described here provides a technical solution to the communication between experimental economics software like z-Tree and biological signal acquisition devices or eye-tracking systems. No specific requirements are prescribed regarding the PC-network managing the two types of software, which allows them to work independently (or even communicate) during the session and synchronize ex post (or during the session) thanks to timestamps. We have found that the *gettime* function overestimates response times by approximately 0.5 seconds.

Interestingly, the latest z-Tree version includes a function (eventtime) that records timestamps directly from the client computers and also enables communication with external devices, computers and programs via IP sockets. Although the client-based eventtime function reduces network-related timing problems, due to the inherent heterogeneity between PCs or background-running software, we can observe different latency jitters in different equipment. The influence of those factors on timing issues is variable and unpredictable. The method we propose and describe here is immune to differences in hardware equipment and laboratory network settings. Even in the case when timing issues are addressed by a stable laboratory setup, our method is essential for an external calibration to ensure network performance and timing precision.

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Table 1: Response times by strategy and treatment for the two-time measurement methods.

	Treatment 1							**Treatment 2**						
	gettime			Diodes			$M\text{-}W^b$	*gettime*			Diodes			$M\text{-}W^b$
	Obs	Mean	St.dev.	Obs	Mean	St.dev.		Obs	Mean	St.dev.	Obs	Mean	St.dev.	
Bribe	825	8.519	8.573	761	7.935	8.649	0.000***	267	6.854	7.538	269	6.122	7.273	0.001***
No Bribe	105	8.940	10.378	109	8.248	9.885	0.151	663	3.968	3.367	631	3.503	3.380	0.000***
$M\text{-}W^a$		0.141			0.291				0.000***			0.000***		

*Significant at 10%, **Significant at 5%, ***Significant at 1%

[a] Mann-Whitney (p-values) for differences across bribe and no bribe

[b] Mann-Whitney (p-values) for differences across time measurement methods