Response durations:

A flexible, no-cost tool for psychological science

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Abstract

Response durations for simple keypress responses are an easily available but heavily underused measure. Whereas response times dominate the toolbox of experimental psychologists and cognitive modelers alike, any study with standard keypress responses also allows for measuring such durations as the time from response onset to response offset. Moreover, response times and durations are decidedly independent so that response durations come with great promise to uncover unique perspectives on cognitive processing. We showcase recent observations and corresponding theoretical frameworks to highlight that this inconspicuous measure deserves much more attention than it has attracted so far. Given that it comes at no extra cost for common experimental setups, any researcher is well advised to consider adding the measures of response durations to their empirical toolbox.

Keywords

Methodology; response duration; performance measures; implicit measures;

1. Response times and response durations

Response times are a staple of experimental psychology. They offer an elegant approach to studying the inner workings of the mind while being remarkably simple to assess; all it takes is measuring the time between the occurrence of a stimulus and the beginning of an overt response.

The current prominence of response times emerged from classical experimentation linking this measure to general principles of psychological processing, including hypothesized relations to intelligence, personality, and atypical mental functioning (Jensen, 2006; Luce, 1986). Crucially, this tradition postulated response time to involve separate processing stages such as perceiving and classifying stimulus information, selecting an appropriate action, and initiating a motor response (Donders, 1869). A major downside of response times was their high moment-to-moment variability, however. Response time measurements therefore firmly established themselves as a go-to measure with the advent of computer technology, which enabled researchers to gather many observations per participant quickly and easily. This database then allowed averaging across many repetitions of the same condition and for fitting sophisticated computational models of evidence accumulation to the observed data (Ratcliff & Smith, 2004).

Typical modeling efforts in psychology and neuroscience capitalize on response times because they focus on the time required to reach a decision threshold (Evans & Wagenmakers, 2020). The same is true for information processing frameworks such as sensorimotor stage models of human cognition, which cover the processes up to movement initiation while not being concerned with any processing that might follow this step (Pashler, 1994). These theoretical traditions thus at least tacitly consider motor execution a mere appendage to cognitive processing and assume later aspects of action execution not to be particularly relevant for psychological theorizing. Actual motor control has therefore been dubbed the Cinderella of psychological science (Rosenbaum, 2005).

The neglect of motor execution in many cognitive approaches stands in stark contrast to a range of fields that do not rely heavily on response time measurements. In fact, some experimental setups obviously invite the study of how movements are enacted, as in the case of movement times for reaching, grasping or pointing actions (Fitts, 1954), similar measures for movements of the mouse cursor and swiping movements on a touchscreen (Wirth et al., 2020), or data on mobility in everyday life (Hinds et al., 2022). The same is true for measures of syllable duration in psycholinguistic studies (e.g., Kawamoto et al., 1998) and for dwell times in eye-tracking research (e.g., Sauter et al., 2021).

Most of these measures promise obvious information gain because they are able to capture, for instance, the difficulty of fine-tuning and coordinating movement as in the case of movement times (Fitts, 1954) or the time needed to extract information from visual input as in the case of ocular dwell times (Holmqvist et al., 2011). Crucially for the present argument, even simple and seemingly ballistic actions like keypresses or taps provide more information than the single measure of response time.

A close cousin of the execution-related measures presented above is the measure of response durations, i.e., the time between response onset (key press) and response offset (key release). Among all possible ways to assess action execution, however, this measure has received particularly little interest in the community so far (also for researchers such as the present authors who have routinely assessed similar variables for more extended movements). This state of affairs is all the more surprising because response durations are part and parcel of any keypress response as employed in countless studies in psychological science and beyond.

Even though response durations have been hiding in plain sight for decades, there are good reasons to assume that this measure has strong potential if it (1) provides unique information that cannot be distilled from response time measurements and (2) if this information can contribute to advancing theories of human cognition and behavior. We discuss both points in the following section.

2. Much promise, little peril

Are response durations a unique source of information, especially as compared to other aspects of a simple keypress response? This is certainly the case as demonstrated by the following examples.

A first way of assessing whether response durations offer information on top of response time data is to compute the correlation of both measures across trials of individual participants (Kello et al., 2007). Figure 1 shows exemplary correlations computed from the publicly available data of a recent study (Foerster et al., 2021).[1] In this study, participants had responded to letter stimuli by pressing either a left or a right key on the computer keyboard according to a stimulus-response mapping rule. Visual noise distractors and a short response deadline aimed at eliciting errors to study error commission. Setting aside the original aim of this study for the moment, we will first focus on correct responses only as commonly done in studies on response times (we will come back to the effect of error commission on response duration later in this section). Computing individual correlations between response time and response duration on a given trial, and averaging these correlations does not show any signs of a systematic relation (r =–.007 in this dataset). A similar pattern arises when correlating mean response time and mean response duration across participants (r = .104). Both measures therefore appear to be remarkably independent with no more than 1% overlap.

[1] Original data available at https://osf.io/3at7x/. Scripts for recreating the figure can be found at https://osf.io/kyz7b/. We thank the editor, Robert Goldstone, for stimulating the visualization in terms of an iso-density plot.

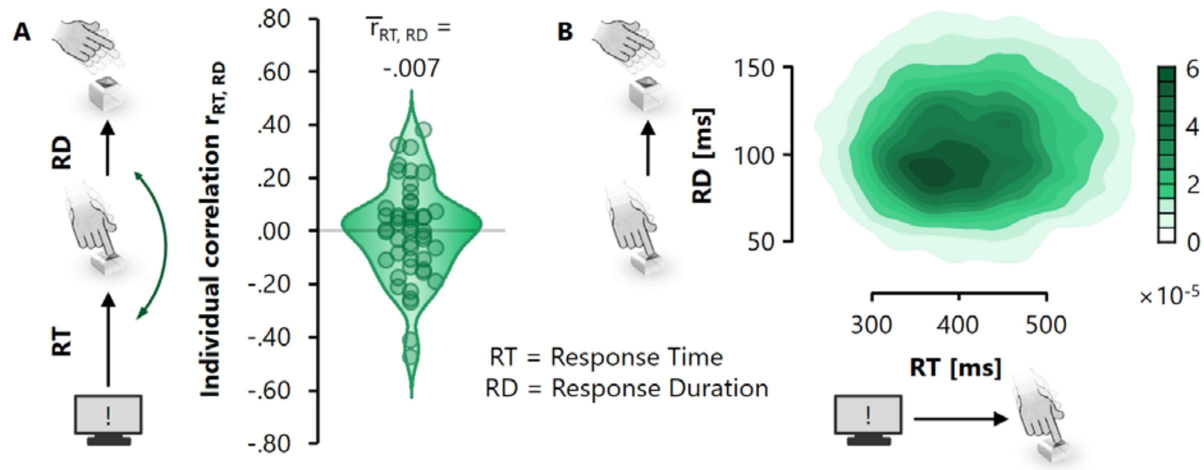

Figure 1. Relation of response duration (RD) to response time (RT) in an exemplary dataset (Foerster et al., 2021; openly available at https://osf.io/3at7x/). Participants of this study classified a target letter with left versus right keypresses, and the figure shows data from correct classification responses. **(A)** Across-trial correlations of RT and RD for each participant (dots). The distribution centers on a correlation of 0, indicating that there is no systematic linear relation between both measures. **(B)** Graphical assessment of potential non-linear relations between RT and RD. The plot shows the pooled data of all participants, with darker shading indicating higher relative frequency (iso-density contours). The pattern again portrays both measures as independent from one another.

A related observation concerns hidden statistical properties of response times and response durations when using time series analyses to assess how these measures evolve across multiple responses. Here, research on human response times has suggested that this measure follows general laws of complex, self-organizing systems (Gilden et al., 1995). This becomes evident when partitioning the overall variability of response times into relatively slow fluctuations of the performance level on the one hand (i.e., extended periods of overall better or worse performance), and fast moment-to-moment fluctuations on the other hand. Complex, self-organizing systems typically show a strong contribution of slow relative to fast fluctuations, and this pattern reliably emerges for response times as well. Intriguingly the same type of fluctuation is also present in response durations but the fluctuations of both variables are independent from one another. That is, experimental manipulations–e.g., predictable versus unpredictable stimuli, including versus excluding preview of upcoming stimuli–have independent effects on the fluctuation of response times and response durations, indicating that both measures carry distinct information (Kello et al., 2007).

Observing response durations to be independent of response times suggests that this measure might indeed be a worthwhile addition to the empirical toolkit of psychological scientists. Yet, it is only useful if it provides relevant insight into cognitive processing. By now, there is converging evidence in support of this claim (e.g., Foerster et al., 2022; Grosjean & Mordkoff, 2001; Kello et al., 2007; Neszmélyi & Horváth, 2018; Pfister et al., 2022).

Research on action slips is a recent example for the added value of analyzing response durations. This field of research has commonly used neurophysiological techniques to assess when and how errors are detected and how these events are processed (Gehring et al., 2012). Several theoretical models have emerged from such findings, positing that it takes about one tenth of a second after committing an error to detect the action slip. However, recent findings suggest that durations for erroneous responses are often shorter than this timescale, whereas correct actions come with substantially longer response durations (Foerster et al., 2021; Hochman et al., 2017). Moreover, this pattern cannot be explained by other corollaries of error commission such as response times of force output of erroneous responses (Foerster et al., 2022). These findings show that starting and finishing a response can be related to distinct cognitive processes. In this case, response durations capture early behavioral adaptation to error commission, suggesting that erroneous actions are cancelled on a surprisingly short timescale that had previously been related to detecting rather than cancelling erroneous actions. Findings from response durations thus challenge current models of error processing and therefore come with the potential to contribute to refining theoretical approaches to cognition and behavior.

A particular selling point of response durations is that this measure does not involve any added cost, because response durations come as a necessary corollary of any response. That is: While previous suggestions for additional behavioral measures have pointed towards the promises of expanded setups (Abrams & Balota, 1991; Kramer et al., 2021), response durations can easily be measured in almost any setup that is used to gather response time data, and they do not require efforts to employ additional experimental apparatus. This is at least true when researchers are willing to accept a somewhat limited measurement precision compared to common response time measurements (e.g., when using standard computer keyboards, which tend to sample keypresses at higher rates than key-releases). While this limitation can be overcome by using specialized equipment, analyses of response durations can yield promising results already with the precision offered by usual technology (Foerster et al., 2021), and even when running web-based studies.

The ease of implementation also sets response durations apart from other properties of keypress responses such as their force profile (Giray & Ulrich, 1993). Response force has been highlighted as a particularly elegant measure already in the early days of experimental psychology, because force can be regarded as a basic output quantity of the human body (Bates, 1947; see also Fitts, 1951). Response force has therefore been used as a unique source of information about cognitive processing (e.g., Ulrich et al., 1998) with particular promise as an implicit measure of decision confidence (Abrams & Balota, 1991). While measuring response force requires dedicated recording equipment and sophisticating analysis procedures, response durations can be readily assessed and thus mined for relevant information.[2]

Fully taking advantage of a measure does not only require the technical means to assess it, however. It also requires a solid theoretical understanding of what this measure actually captures. We will cover this point in the next section.

3. Interpreting response times and durations

Many psychological scientists find it intuitive to interpret data from response time experiments. This measure is commonly taken to reflect a series

[2] Given the ease of recording response durations, it feels tempting to use durations as a proxy for response force. Our data suggest a moderate correlation for this purpose with about 50% shared variance between response durations and peak force and 60% shared variance for response durations and impulse size (i.e., force by time; calculated from the data of Foerster et al., 2022).

of component processes, such as perceiving and classifying perceptual events, selecting an appropriate course of action, and initiating a body movement (Fig. 2). The seemingly intuitive nature of this measure, however, builds on long-lasting efforts to understand its underlying psychological processes. About 200 years ago, for example, many scientists were still convinced that basic psychological functions such as perceiving a visual object would not require a noticeable amount of time (see Woodworth, 1938, for a historical sketch). Only continued, systematic experimenting was able to change this misconception by establishing that response times relate to a series of psychological processes in preparation of an overt response (Donders, 1869; see also Jensen, 2006; Luce, 1986).

A similar database has yet to be established for the case of response durations. While response time data was scrutinized by many experimental psychologists in the early 20th century, common textbooks of that era either did not discuss the execution of keypress or key-release responses at all, or they considered it an “after-period” that did not warrant extended discussion (e.g., Woodworth, 1938, p. 310). A rare exception is early work that discussed response durations as “recovery time” or “restart time” (Hirsch, 1936; Ponzo, 1936).[3] The present proposal indeed echoes these seminal observations, because they had already proposed response durations to capture continued

[3] This work, published by prominent researchers in Italian and French journals, does not seem to have drawn attention of the wider scientific community, though. A major factor contributing to this neglect likely was the complex experimental apparatus that was required to assess response durations at the time (Ponzo, 1936). This obvious obstacle is easily overcome with standard computer technology.

processing of the response while also observing this duration to be uncorrelated with response times. These articles further suggested using such durations as a diagnostic tool in personnel selection to measure a candidate's psychomotor efficiency. Interest in response durations had shortly spiked for technical reasons as well, when human factors engineers noticed that keypress durations were critical when operating mechanical typewriters (e.g., Lahy, 1927). Here, pressing a key while still holding down the previously pressed one would result in equipment malfunction such as the type hammers entangling and thus interrupting performance. After (mechanical) typewriters had given way to refined computer technology, keypress durations were no longer studied systematically in applied psychology and human factors. In any case, this field highlighted that response durations were an integral part of any keypress response, likely reflecting the duration of cognitive mechanisms that monitor ongoing behavior.

Theorizing on human motor control offers several elegant concepts to refine the notion of monitoring. This is particularly true for models that provide an economic perspective on cognitive effort and metabolic costs involved in controlling body movements (e.g., Shadmer et al., 2016). Monitoring has to accommodate two opposing goals in this view: For one, an action has to be performed for a sufficient amount of time with sufficient force to register if an intended movement unfolds as planned. For another, force and duration of an action should be kept to a minimum to avoid undue metabolic investment. Several recent observations are consistent with this view. One corresponding example is that keypress or finger-pinch actions that trigger reliable auditory feedback come with low force and short duration as compared to superficially similar actions without auditory feedback (Neszmélyi & Horváth, 2018). Reducing the reliability of feedback signals, in turn, increases response force and duration. Such observations are consistent with the idea that participants use additional body-unrelated feedback for motor optimization, i.e., for shifting the balance towards lesser motor effort (Karlovich & Graham, 1968; Varga et al., 2022).

Taken together, response durations thus reflect monitoring efforts to establish whether a movement unfolds as intended while minimizing metabolic energy investment. This view portrays response duration as especially tailored to studying online adjustments of performance. Several intriguing additional applications present themselves, however, as sketched below.

4. Applications

Having a solid understanding of the processes underlying response times and response durations allows for informed inferences from these measures as summarized in Figure 2.

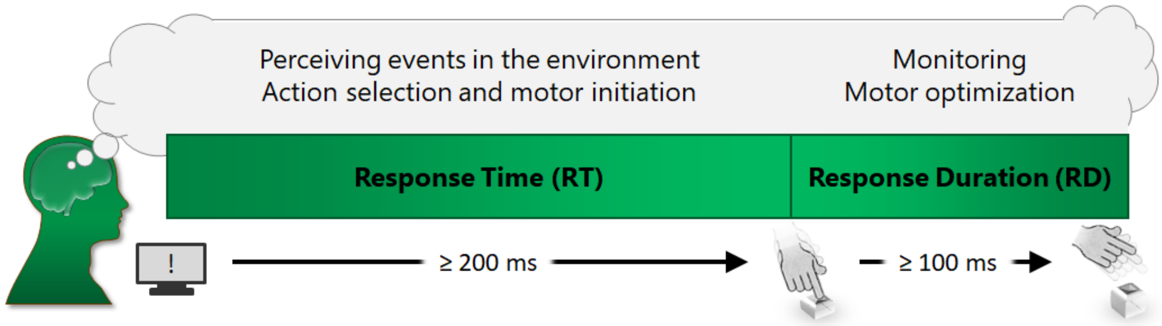

Figure 2. Psychological processes affecting response times and response durations. The processes of perception, action selection, monitoring, and motor optimization may each include different components corresponding to the experimental setup. Crucially, both measures can be used to study any variable that affects at least one of the listed components. If, for example, (un)certainty can be assumed to affect monitoring demands, such an impact will be readily observable when assessing response durations. The same holds true for previous events that cause response times or response durations to adapt for later responses. Finally, response durations can be expected to be sensitive to upcoming demands such as subsequent actions in an action sequence.

The emerging view discussed so far only represent the tip of the iceberg of potential applications of response duration as a means to study human cognition and behavior. Because response durations can be assessed in any study measuring response times, future work would be well advised to look for systematic effects across diverse fields of psychological inquiry. For instance, response durations have been observed to be affected by upcoming task demands with shorter response durations the sooner the agent expects to perform a new movement (Vaughan et al., 1998). The same work also observed hysteresis effects in the sense that response durations are affected by immediately preceding actions. Instructing participants to produce responses of specific durations has also been used to study motor programming (Klapp & Rodriguez, 1982) or stimulus-response compatibility effects (Kunde & Stöcker, 2002). Yet, a particularly elegant property of response durations is that participants usually spend little thought on this aspect of their behavior if not specifically instructed to do so. Promising future directions therefore include the use of response durations as an implicit measure for relevant concepts such as choice confidence and (un)certainty as these variables likely affect monitoring demands (Gawronski & Hahn, 2019).

5. Conclusions

Response durations are available at the fingertips of any researcher running studies with simple keypress responses. Routinely measuring and analyzing this property of how a response is enacted provides a powerful addition to any study on human cognition. The high promise of recording and analyzing response durations for simple keypress responses should of course be seen as supplementing rather than replacing other measures of action execution (Rosenbaum, 2005), because a maximally diverse set of measures is key to making exciting discoveries about cognition and behavior. Whenever a researcher opts to conduct a study involving any type of keypress reaction, however, recording the innocuous measure of response durations may yield precisely such a discovery.

6. Recommended readings

Rosenbaum (2005, see References). An engaging view on how the peculiarities of actually performing a body movement have become the Cinderella of psychology, including a vibrant plea to overcome this state of affairs.

Kello et al. (2007, see References). Convincing analyses to show that the duration of simple keypress responses contains valuable information that is distinct from the information conveyed by response times.

Foerster et al. (2022, see References). The reported findings on error cancellation showcase how traditional theorizing can be challenged by analyzing response duration in common experimental setups.

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