Does working memory load lead to greater impulsivity? Commentary on Hinson, Jameson, and Whitney's (2003)

ANA M. FRANCO-WATKINS, HAROLD PASHLER & TIMOTHY C. RICKARD
University of California, San Diego

Previous research by Hinson, Jameson, and Whitney (2003) demonstrated that a secondary task in a delayed discounting paradigm increased subjects' preference for the immediate reward. The authors interpreted their findings as evidence that working memory load results in greater impulsivity. We conducted a reanalysis of the data from Hinson et al.'s Experiment 1 at the individual subject level. Difference scores were calculated by subtracting the digit memory load condition from the control condition for *k* (discounting parameter) and a measure of "erroneous" responses. The results indicated that the secondary task increased random responding, which in turn can account for the increased mean estimates of *k*. Thus, the data do support the claim that cognitive load affects impulsivity per se.

The tendency to discount larger rewards that are delayed in time, and to choose immediate smaller rewards, have been well established in the literature (see Green & Myerson, 2004 for a review; Kirby & Marakovic, 1995; Rachlin, Raineri, & Cross, 1991). This phenomenon is often referred to as delayed discounting or temporal discounting and has been argued to play an important role in many socially problematic phenomena, such as substance abuse (Kirby & Petry, 2004) and criminality (Nagin & Pogarsky, 2004).

Several studies have begun to explore the cognitive processes underlying delayed discounting (e.g., Green & Myerson, 2004; Prelec & Loewenstein, 1991; Rachlin et al., 1991; Zauberman & Lynch, 2005). In one such effort, Hinson, Jameson, and Whitney (2003) proposed that temporal decision making taxes working memory, leading the immediate reward to be overvalued, due to an inability to adequately consider and weigh the value and magnitude of the larger delayed reward. In support of this hypothesis, Hinson et al. (2003) found that a secondary task increased preference for the immediate reward, an effect that they interpreted as an increase in impulsivity.[1] In this paper, we will address this issue further by re-examining the data from Hinson et al.

In Hinson et al.'s (2003) Experiment 1, the primary task, a decision task, required subjects to select which of two options he or she preferred. Choice 1 consisted of a certain amount of money (ranging from \$100 to \$1000) available immediately. Choice 2 consisted of a larger sum (ranging from \$1200 to \$2000) available only after a delay ranging from 1 week to 24 months. While making decisions about the preferred choice, subjects completed one of three levels of working memory load. The *digit memory condition* required subjects to view a string of five random digits. This was followed by a recall test, in which a probe digit

Corresponding Author: Ana M. Franco-Watkins
Department of Psychology, University of California, San Diego, 9500 Gilman Drive #0109, La Jolla, CA 92093-0109, afrancow@ucsd.edu

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[1] Although there are several ways to operationalize impulsivity, following Hinson et al. we define impulsivity as the preference for the immediate reward over the larger delayed reward.

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was displayed, and subjects recalled the digit to the right of the probe digit. Inserted between the digit string display and the recall was the decision task. In the *random generation condition*, after making a decision, subjects produced a random single digit. The *control condition* required subjects to press a key that corresponded to a single digit displayed on the screen. In all conditions, the subject performed the secondary task after completing the decision task. However, the digit memory condition appeared to be the only condition that required processing during the decision task (a point we elaborate upon later). Note that the experiment was initially designed such that both the digit memory condition and random generation condition would tax the central executive of working memory.

The results from Hinson et al. (2003) suggested that there was a shift toward impulsivity under cognitive load, but only for the digit memory task. Impulsivity was measured by the value of the discounting parameter, k. Larger values of k correspond to greater amounts of discounting. Although several mathematical functions have been used to describe the rate of delayed discounting, the hyperbolic function has received the most support in the literature (Green & Myerson, 2004; Kirby & Marakovic, 1995; Rachlin et al., 1991).[2] The hyperbolic function is represented by the following equation:

$$V = A / (1 + k\,D)$$

(Eq. 1)

where V refers to value, A represents the monetary amount in the choice option, k is the discounting rate, and D is the amount of the delay.

In their Experiment 1, Hinson et al. (2003) reported mean k values of .646, .351, and .301, in the decision task for the digit memory, random number generation, and control conditions, respectively. The mean k for the digit memory condition was significantly greater than for the other two conditions. Based on these results, Hinson et al. concluded that increased demand on working memory results in greater impulsivity within the delayed discounting paradigm. These results paralleled other results obtained when secondary tasks were coupled with a gambling decision task (Hinson, Jameson, & Whitney, 2002; Jameson, Hinson, & Whitney, 2004).

Reanalysis of Hinson's et al.'s (2003) Experiment 1

The phenomenon reported by Hinson et al. (2003) is certainly intriguing, and might have potential application to a number of important real-world phenomena. Before accepting the authors' interpretation, however, it seemed to us that a more detailed examination of the results at an individual subject level might be illuminating. In particular, we were interested in the possibility that the working memory load conditions might have affected responding not by altering subjects' preferences and making them more impulsive, but instead by making their judgments more random.

In reexamining the data from Hinson et al.'s (2003) Experiment 1[3], we first estimated k for each subject and condition, as Hinson et al. had done.[4] The results confirmed the findings of Hinson et al. with respect to the mean k values. We then calculated two difference scores for each subject: a) k for the digit memory condition minus k for the control condition, and b) number of "erroneous" responses in the decision task in the digit memory condition minus the number of “erroneous” responses in the control condition. By erroneous responses, we refer to the number of choices made in the decision task which differed from the responses that would be predicted for that subject and that choice based on the best-fitting value of k. A scatter plot of the k difference scores as a function of the error difference scores is shown in Figure 1. The greater number of positive than negative k difference scores in the figure reflects Hinson et al.'s findings

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[2] Green and Myerson (2004) demonstrated that an exponential hyperbolic provides a slightly better fit to the delayed discounting data, but we will use the hyperbolic with the single free parameter.

[3] Values for equation 1 were assessed for the immediate and delayed options by varying k values in incremental steps. An error occurred when the subject's choice disagreed with the estimated higher value option. For all errors, the sum of squared error was calculated between the two values. The k yielding the smallest total sum of squared errors was the reported estimated k per subject per condition.

[4] We are very grateful to John Hinson for providing us with the raw data from their Experiment 1.

with respect to the mean values of *k*. Note, however, the significant positive correlation (r = .88, *p* < .01) between the *k* difference scores and the error difference scores.

Figure 1 allows us to discriminate between two candidate accounts of the results for the mean values of *k*. One possibility is that the effect of load is purely to produce more impulsivity as noted by Hinson et al. (2003). In this case, there should be no correlation between *k* difference scores and error difference scores– a prediction that is inconsistent with the pattern in Figure 1. Another possibility is that load does not actually change impulsivity, but simply increases the percentage of trials on which subjects respond randomly. This strategy must result in a poorer model fit, with corresponding increases in errors under load, as was the case for some subjects (see Figure 1). If subjects selected the immediate option 50% of the time in the control condition, then this model predicts no correlation between the *k* difference scores and the error difference scores in Figure 1, because with random responding the immediate option would still be chosen about 50% of the time in the digit memory condition. However, in this experiment, subjects on average selected the immediate option only 25% of the time in the control condition and 30% of the time in the digit memory condition. When the delayed option is preferred to the immediate option, the act of random responding on some trials must increase the percentage of trials on which subjects select the immediate option (consider the extreme case in which a subject randomly responds on every trial) which naturally leads to an increase in *k* values. Thus, for this experiment, the random responding model predicts the observed correlation between *k* difference scores and error difference scores. Note that the random responding model predicts that *k* would *decrease* (the reverse correlation) in an experiment where subjects preferred the immediate option.

Inspection of Figure 1 might suggest that the correlation between the error difference score and the *k* difference score is being driven solely by the three outliers in the upper quadrant of Figure 1. Removing these outliers, however, resulted in *r* =.53, *p* < .01. Furthermore, the same correlation was found in a comparison of random generation condition and the control condition, r = .40, p < 01, even though the random generation condition appears to have been a less demanding load condition.

To further explore the effects of random responding on the *k* values, we simulated the effects of random responding by randomly assigning one of the two responses (immediate or delayed) to a randomly selected subset of each subjects' trials using the data from Hinson et al.'s (2003) control condition. We introduced random responding at a rate of 5% (i.e., 3 trials) and further simulated random responding with a series of 5% incremental increase. Each time the rate was incremented, a new random subset of trials was used in the simulation as well as new computation of *k*. Figure 2 shows the results for *k* as a function of increasing random responding rate.[5] The *k* value at zero random responding represents the value obtained by Hinson et al. for the control condition. As can be noted from the figure, there was a marked increase in *k* as the rate of random responding increased. Interestingly, the values of *k* obtained in the simulation when there was 100% random responding is very close to the value of *k* obtained for the three outlier subjects in the upper right quadrant of Figure 1, suggesting that those subjects were responding randomly on every trial. This interpretation implies that those three subjects selected the immediate option about 50% of the time, and in fact their mean rate of immediate responding in the digit memory condition was 51%, contrasted to the group average of 30% in that condition. Thus, the random responding model alone can account for the correlation between *k* difference scores and the error difference scores in this experiment, without the need to posit an increase in impulsivity. Our interpretation is consistent with research findings in the calibration judgment research whereby accounting for random error affects the interpretation of the data (Budescu. Erev, & Wallsten, 1997; Erev, Wallsten, & Budescu, 1994).

Lastly, note that a hybrid model, according to which an increased working memory load results in both an increase in random responding and an increase in impulsivity, can also be rejected for two reasons. First, the hybrid model incorrectly predicts both a positive correlation between *k* difference and

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[5] Simulated data is based on the average of 25 simulations.

error difference scores (as a consequence of the random responding component) and also a positive intercept (i.e., the difference in *k* should be greater than zero when the difference in error is zero). Second, as noted above, the greatest difference in *k* that was observed is within the range that can be accounted for by random responding alone. Thus, even for the few subjects who are driving the mean increase in *k*, there is no evidence of increased impulsivity under load.

Theoretical and Methodological Implications

How does one reconcile our results with Hinson et al's (2003) theory of the effects of working memory on impulsivity? Our reanalysis does not challenge their basic claim that working memory load can affect decision processes. It does, however, imply that their conclusions should be modified in two important respects. First, our results show that an individual difference approach is needed to fully understand the effects of working memory load on a subject's decision behavior. One could maintain that the few people who had larger discounting rates under load might also have lower working memory capacity, and that this capacity limitation might have resulted in increased random responding. That hypothesis remains to be examined, although individual differences in working memory capacity have been shown to correlate or predict performance on various tasks, such as note taking, following directions (Engle, 1996), verbal fluency (Rosen & Engle, 1997), and proactive interference (Kane, Bleckley, Conway, & Engle, 2001; Kane & Engle, 2002; see Engle, 2002 for a brief overview). Second, Hinson et al.'s (2003) data provide no evidence that the effect of working memory load is to increase impulsivity. Instead, the data suggest that working memory load results in an increased rate of random responding for a subset of subjects. Practically speaking, the prospect that load results in random responding is no less interesting than the possibility that it results in impulsivity. Indeed, if as a general rule working memory load is shown to produce random responding, then the consequences of that load may be even more devastating on performance than the alternative case in which subjects can at least rely on a simplifying heuristic, such as preferring the immediate option or the option having the greatest magnitude of reward. On the other hand, the random responding under load for a subset of subjects may be more an artifact of the experimental context than a property of real world behavior. It is uncertain whether random responding would occur when something important to the subject is at stake.

The finding that greater random responding did not occur for most subjects might be due to the fact that the secondary tasks were not sufficiently taxing on the working memory system, particularly the executive control component of working memory. Both digit memory and random generation tasks have been used in other reasoning studies as secondary tasks and did produce substantial working memory load. However, the secondary task in those studies occurred concurrently and verifiably with the reasoning task. For instance, when a digit memory condition is used subjects are instructed to vocally rehearse the digits while doing the reasoning task (Evans & Brooks, 1981; Toms, Morris & Ward, 1993; and similarly when letters are used instead of digits: Halford, Bain & Mayberry, 1984). In contrast, in the Hinson et al. (2003) experiment subjects were not required to vocally rehearse, raising the question as to the extent of involvement of the working memory system in their experiment. In addition, the number of digits used in the digit memory condition, five, might not have been enough to create high working memory demands for most subjects. For example, Baddeley, Lewis, Eldridge & Thomson (1984) demonstrated digit load leads to increased reaction time and errors in the primary task, and the effect was larger as the number of digits (e.g. 6 to 8) increased in the secondary task.

The lack of performance difference between the random generation condition and the control condition in the Hinson et al. (2003) design is most likely due to the fact that generating a single random digit at the end of the decision task does not place much demand on cognitive processing during the decision task. Typically, the random number generation task occurs concurrently with the reasoning task, with generation occurring every second or two (e.g., Gilhooly, Logie, Weatherick, & Wynn, 1993; Logie & Salway, 1990; Messier, Klauer, & Naumer, 2001).

Conclusions

We have argued that Hinson et al.'s (2003) finding that working memory load increases impulsivity appears to be an artifact of a greater rate of random responding by a few subjects. It appears that working memory load, as operationalized by their digit memory task, does not play a major role in delayed discounting behavior for most subjects. Further support for this notion is derived from Experiment 4 in Hinson et al., where the digit load condition failed to have the same reliable effect on *k* as it did in Experiment 1.

Hinson et al. (2003) deserve credit for their efforts to delineate the role of working memory, and more specifically executive control, on time based decisions. Our conclusions do not imply that working memory plays no role in decision processes (see Hinson et al., 2002; Jameson et al., 2004 for examples of the role of working memory in a gambling task). Rather, further research is needed, using more potent dual-task manipulations, before any strong conclusions can be drawn about how temporal preferences may be affected by working memory load.

Postscript

In their response to our commentary, Hinson and Whitney (in press) note that the correlation between *k* difference and error difference scores is non-significant when four outliers are removed as well as when the data from Experiment 4 were analyzed. However, only three of those data points were outliers, based on a traditional classification of 2.5 standard deviations above the mean (on both measures). A significant correlation remained when those three data points were removed. Note that these "outliers" deviate in their *k* difference scores just as predicted by the random responding hypothesis (given their error difference scores), raising questions about whether they should be treated as spurious. Hinson and Whitney also point out that there was no correlation between *k* difference and error difference scores in Experiment 4 (see their Figure 1) despite small increases in the mean *k* value under digit memory load. First, as in Experiment 1 (see our Figure 1), it appears that the increase in *k* under working memory load is driven by a small subset of subjects. Most subjects exhibited no increase in their *k* difference scores, indicating no increase in impulsivity under working memory load. Further, the magnitude of the increase in the *k* difference score for those few subjects is much smaller than for the subset of subjects responsible for the effect in Experiment 1. Third, it is unclear whether the pervasive preference for the delayed response in Experiment 1 was also present in Experiment 4. Several changes in stimulus materials suggest that it might not have been the case. If both choice options were selected about 50% of the time in Experiment 4, then there should not be a correlation.

Lastly, Hinson and Whitney present the mean *k* values across 20 sets of trials to indicate that their digit memory condition was sufficient to induce working memory load. It is unclear, however, whether the increase in mean *k* value across trials is due to proactive interference (as indicated by Hinson and Whitney), increased fatigue or increased random responding. Any or all of these could produce an increase in *k*. Thus, despite the points raised by Hinson and Whitney; the data would seem quite insufficient to allow us to conclude that choice performance under the digit memory load reflects increased impulsivity.

Author Note

Ana M. Franco-Watkins, Harold Pashler, and Timothy C. Rickard, Department of Psychology, University of California, San Diego.

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Correspondence concerning this article should be addressed to Ana M. Franco-Watkins, Department of Psychology, University of California, 9500 Gilman Ave, 0109, San Diego, La Jolla, CA 92093. E-mail: afrancow@ucsd.edu.

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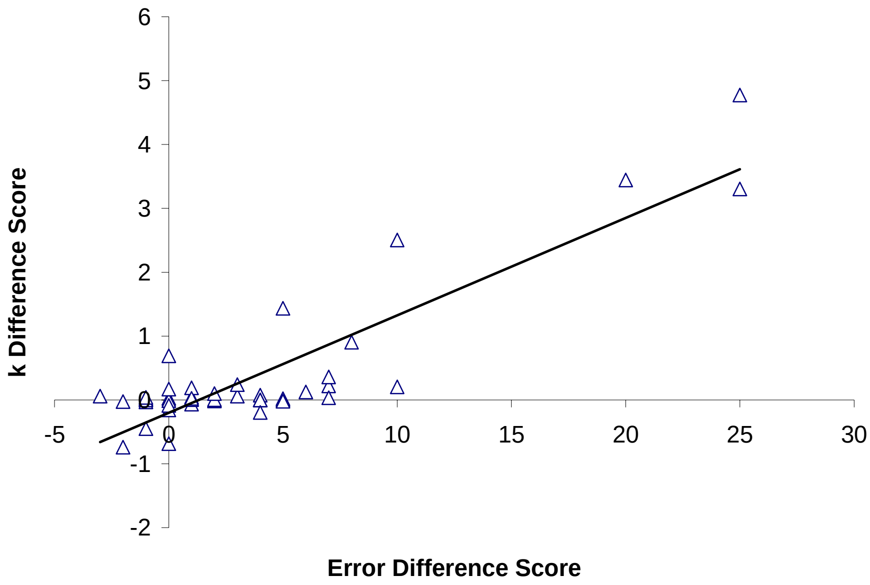

Figure 1. Hinson et al's (2003) Experiment 1 plotted as a function of *k* difference score and error difference score per subject.

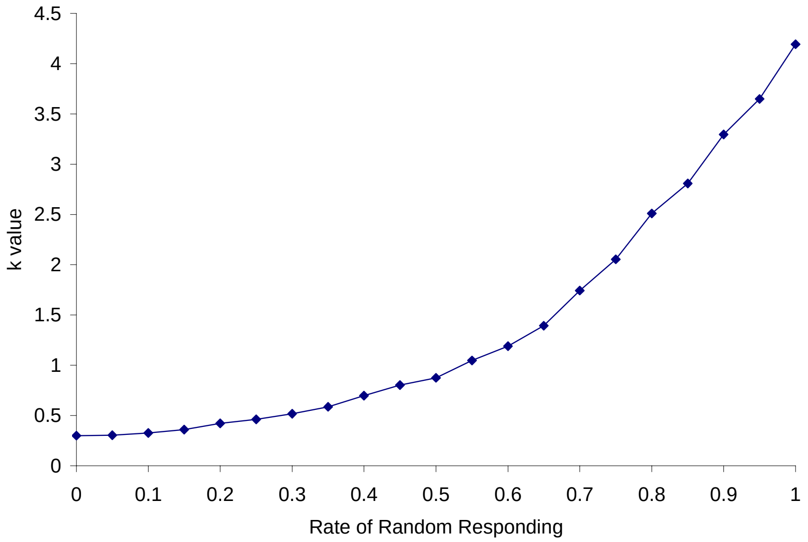

Figure 2. Simulated *k* values based on introducing different rates of random responding to Hinson et al.'s (2003) control condition in Experiment 1.