Stocks and losses, items and interference: A reply to Oberauer and Süß (2000)

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Results of a recent study of spatial working memory are presented in support of the claim by Jenkins and her colleagues (Jenkins, Myerson, Hale, & Fry, 1999) that secondary tasks produce larger interference effects in individuals with higher simple spans than in individuals with lower simple spans. Because spans and interference effects were assessed independently, this study refutes the claim by Oberauer and Süß (2000) that the relation between span and interference effect size is merely an artifact of regression to the mean. In contrast with the present findings, Oberauer and Süß did not find evidence of larger interference effects in higher span individuals, but the reason for this may be straightforward: The secondary tasks that they used did not produce significant interference. Recent findings by Logie and his colleagues indicate that phonological similarity and word length effects are larger in individuals with higher word spans (Logie, Della Sala, Laiacina, Chalmers, & Wynn, 1996). These results, those of Jenkins, Myerson, et al. (1999), and the results reported here suggest that, across individuals, the absolute effect size for many manipulations that decrease memory span is an increasing function of simple span.

When the stock market goes down, individuals' losses are principally determined by two factors. One factor obviously is which stocks they own, but if the decline is sufficiently broad based, the major factor may be simply how much money they have invested or how many shares they own. For any given stock, the more shares they hold, the greater their loss is likely to be. The results of a re-

cent meta-analysis (Jenkins, Myerson, Hale, & Fry, 1999) indicate that, similarly, the more items individuals hold in working memory, the more items they are likely to lose when they perform a secondary task. This suggests that the representation of each item may be at risk when secondary task responses either interrupt rehearsal or introduce new information, and for span-length lists the degree of risk is independent of the number of other items. The result, simply put, is that "the more you have, the more you have to lose."

When Jenkins and her colleagues (Jenkins, Myerson, et al., 1999) examined the effects of secondary tasks on working memory across the life span, they found little evidence of a systematic developmental trend in interference effects (i.e., the difference between span without a secondary task, or *simple span*, and span with a secondary task, or *complex span*). Within each age group, moreover, individuals who had larger simple spans tended to show larger interference effects than did individuals who had smaller simple spans. These results are not easily explained by current working memory theories, particularly those that emphasize the role of inhibition and susceptibility to interference in explaining individual and age differences (see, e.g., Dempster, 1992; Engle, Tuholski, Laughlin, & Conway, 1999; Hasher & Zacks, 1988). However, it is to be hoped that the simple stock market analogy just outlined will make these findings seem less counterintuitive.

Oberauer and Süß (2000), in their recent commentary, did not challenge Jenkins, Myerson, et al.'s (1999) conclusions regarding the lack of systematic age trends in interference effects, but they did object to Jenkins, Myerson, et al.'s conclusions regarding individual differences in interference effects on both methodological and conceptual grounds. From a methodological (or statistical) perspective, Oberauer and Süß claimed that Jenkins, Myerson, et al.'s results with respect to individual differences were an artifact of regression to the mean, resulting from the unreliability of memory span measures. From a conceptual (or theoretical) perspective, Oberauer and Süß claimed that regardless of the results, such data are not relevant to an interference/inhibition account of working memory, because simple and complex span tasks measure different constructs, and only complex spans involve inhibition. As a result, they contended, an interference/inhibition account does not predict smaller interference effects in individuals with larger simple spans.

We take issue with the latter position, but our argument would probably be moot if Jenkins, Myerson, et al.'s (1999) original conclusions were shown to be false. Therefore, we shall begin by presenting evidence that deals with Oberauer and Süß's (2000) methodological objection and that supports Jenkins, Myerson, et al.'s conclusion that high-span individuals are more affected

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than low-span individuals by interference from secondary tasks.

Do Higher Span Individuals Show Larger Interference Effects?

Psychologists have long known that measurement error attenuates the slope of a regression line (e.g., Isaac, 1970). Oberauer and Süß's (2000) account of this problem, however, is only partially correct and appears to confuse correlation with regression. Specifically, it is not true, as Oberauer and Süß assert, that "the slope of the regression line decreases with decreasing reliability of the variables involved" (pp. 727–728). This statement is only strictly true in the case of correlation in which the variables are standard scores (i.e., *Z* scores) and the slope is the correlation between the variables. In the case of least squares regression more generally, the expected value of the slope estimate is unaffected by the reliability of the criterion (*Y*) variable, although the reliability of the slope estimate is obviously affected (Linn & Werts, 1982).

In contrast to the lack of effect of criterion reliability, the reliability of the predictor (*X*) variable does affect the expected value of the slope of the regression line (Fuller, 1987). Specifically, measurement error in the predictor attenuates the slope—this being the well-studied problem of error in *X* (for a historical review, see Sprent, 1990)—resulting in the phenomenon known as regression to the mean. The issue of attenuation of regression slopes is relevant, because the pattern of individual differences reported by Jenkins, Myerson, et al. (1999) was revealed by the regression of complex span on simple span. For all age groups, the regression slopes were considerably less than 1.0 for both digit and location spans, indicating that the difference between simple and complex spans (i.e., the size of the interference effect) was an increasing function of simple span. The substantive question, however, is not whether the slopes reported by Jenkins, Myerson, et al. were underestimated (they were, as Jenkins, Myerson, et al. pointed out in their article), but whether that underestimation led Jenkins, Myerson et al. to an incorrect conclusion.

Do individuals with larger simple spans really suffer greater interference from secondary tasks, as Jenkins, Myerson, et al. (1999) concluded? Jenkins and her colleagues recently conducted an experiment that focused directly on this issue and that was specifically designed to deal with the problem of regression to the mean. The data obtained from the first group of 60 young adults in this study were reported at the Psychonomic Society meeting in the year before publication of the meta-analysis (Jenkins, Hale, & Myerson, 1998). At the following meeting (Jenkins, Myerson, & Hale, 1999), these results were compared with those from a second group of 50 older adults. The findings of this experiment that are most relevant to the concerns raised by Oberauer and Süß (2000) are summarized briefly below, but for a more detailed de-

scription of all of the conditions and their results, we refer readers to Jenkins, Myerson, and Hale (2000).

This latest experiment by Jenkins and her colleagues focused specifically on spatial working memory (Jenkins et al., 1998; Jenkins, Myerson, & Hale, 1999). The primary memory task was similar to the original spatial span task described in Jenkins, Myerson, et al. (1999), but the new procedure added three important features. First, participants recalled locations by touching cells in a grid displayed on a touch-screen monitor, and second, memory span was measured using a psychophysical staircase procedure (for details, see Jenkins, Myerson, Joerding, & Hale, 2000). Third, and most importantly, performance on the primary span task alone (i.e., with no secondary task) was assessed twice.

Participants were tested on a battery of speeded visuospatial processing tasks as well as a variety of working memory task conditions that assessed their memory span for spatial locations, and the time that it took them to perform secondary tasks was also measured. For our present purposes, we will focus on the simple span conditions and the two complex span conditions that involved spatial secondary tasks, because these conditions most closely parallel those analyzed in Jenkins, Myerson, et al. (1999). In both of these complex span conditions, the secondary tasks required participants to use information from the stimuli for the primary memory task. These stimuli consisted of series of colored $\times$ s displayed one at a time in the cells of a grid.

In the *single-touch* complex span condition, the spatial secondary task required participants to touch the circle (one of six differently colored circles displayed to the right of the grid) that was the same color as the $\times$ (see Figure 1 in Jenkins, Myerson, et al., 1999). In the *double-touch* complex span condition, the spatial secondary task had an additional requirement. After participants touched the circle whose color matched the $\times$, the border of the cell containing the $\times$ changed color, and participants then had to touch another circle (one of a second set of four circles to the right of the grid) whose color matched the cell border. These procedures were designed to be formally analogous to complex span procedures such as the reading span task, a paradigmatic working memory measure (for a recent review, see Daneman & Merikle, 1996). In both cases, a series of stimuli ($\times$ s in a grid or sentences) are presented, and participants must respond to aspects of these stimuli (the colors of the $\times$ s or words other than the final words) that are irrelevant to the primary memory tasks.

At the group level, not surprisingly, both spatial secondary tasks decreased memory span relative to that when there was no secondary task, and the double-touch task produced more interference than did the single-touch task. For the present purposes, however, the more relevant results concern how individual differences in span modulated these effects. Because of the way in which this experiment was designed, it was possible to

assess differences in the amount of interference suffered by lower and higher span individuals by using two quite different analytic approaches. The first approach paralleled that used in the Jenkins, Myerson, et al. (1999) meta-analysis, but because there were two assessments of simple span in the present experiment, it was possible to compare the regression of complex span on simple span with an estimate of the effect of regression to the mean (as provided by the slope of the relation between the two simple span assessments). In the second approach, the participants were divided into subgroups based on the first assessment of simple span in order to compare interference effects, calculated on the basis of the second assessment of simple span, for lower and higher span subgroups. Importantly, the two approaches provided converging evidence consistent with the conclusion originally reached by Jenkins, Myerson, et al.

(1999) that higher span individuals suffer greater interference than lower span individuals do.

Consider the results obtained with the use of the first approach, shown in Figure 1, in which simple spans from the first assessment were used to predict the simple spans from the second assessment as well as the complex spans from the single- and double-touch conditions. Because all three regressions use the same predictor, the error in X is held constant across regressions. The effect of this error is to attenuate the slope (i.e., the slope estimate is some proportion of the true slope), but because the error in X is held constant, the degree of attenuation is the same for all three regressions (Fuller, 1987). Thus, the slopes for the regression of the two complex spans on the first simple span (0.597 and 0.385 for the single- and double-touch conditions, respectively) can be compared directly with the effect of regression to the mean

Figure 1. Regression of simple span (second assessment) and complex span (single- and double-touch) on simple span (first assessment).

as indexed by the slope for the regression of the second simple span on the first simple span (0.842).

Multiple regression analyses revealed that the slopes for the complex spans were both significantly less than that predicted by regression to the mean, indicating that the size of the interference effect produced by secondary tasks was an increasing function of an individual's simple span: for single-touch, $t(216) = 2.57, p = .011$; for double-touch, $t(216) = 5.25, p < .001$. Moreover, the slope for the double-touch condition was significantly less than the slope for the single-touch condition, indicating that the effect of an increase in secondary task difficulty on complex span also depended on an individual's simple span [$t(216) = 2.44, p = .016$]. Thus, the size of the secondary task effect was an increasing function of simple span in all three cases, replicating the results reported by Jenkins, Myerson, et al. (1999).¹ There were no significant differences between the regression parameters for young and older adult groups.

Our second analytic approach involved dividing participants into lower span and higher span subgroups and comparing how the subgroups are affected by secondary tasks. If subgroups are determined on the basis of one assessment and interference effects are calculated on the basis of a second assessment, then measurement error will decrease the power of the comparison but will not systematically bias that comparison. Accordingly, we performed a median split of each age group based on the first assessment of simple span and calculated interference effects based on the difference between complex span and the second simple span assessment. Of the various analyses of variance (ANOVAs) conducted on the data, perhaps the most relevant is a planned comparison of the interference effects in the single- and double-touch conditions for higher and lower span young adults and higher and lower span older adults. This comparison directly addresses the issue of how age and ability affect the amount of interference produced by secondary tasks.

The ANOVA revealed significant effects of age (young vs. old) and ability (lower vs. higher span) [$F(1,106) = 13.37, p < .001$, and $F(1,106) = 8.17, p < .01$, respectively]. These main effects reflect the fact that the interference effects of young adults were larger than those of older adults, and the interference effects of higher span individuals were larger than those of lower span individuals. The difference between the interference effects of higher and lower span individuals was observed in each age group, and there was no age $\times$ ability interaction [$F(1,106) < 1.0$]. There were, however, significant interactions between secondary task (single- versus double-touch) and both age and ability [$F(1,106) = 21.71, p < .001$, and $F(1,106) = 11.14, p = .001$, respectively]. There was no three-way interaction [$F(1,106) < 1.0$].

The interactions with secondary task reflect the fact that the difference between young adults' single- and double-touch interference effects was greater than the difference between older adults' single- and double-touch interference effects, and that the difference be-

tween higher span individuals' single- and double-touch interference effects was greater than the difference between lower span individuals' single- and double-touch interference effects. These interactions are consistent with what would be expected from the regression analyses and inspection of Figure 1. The increasing difference between the single- and double-touch regression lines with increases in simple span in that figure, for example, corresponds to the ability $\times$ secondary task interaction in the ANOVA.

The converging evidence from the ANOVA and regression analyses contradicts Oberauer and Süß's (2000) suggestion that our earlier conclusions merely reflect an artifact of regression to the mean. Why did we find evidence of larger interference effects in higher span individuals, whereas Oberauer and Süß did not? The reason may be straightforward: The secondary tasks used by Jenkins and her colleagues produced significant decreases in memory span, whereas the secondary tasks that Oberauer and Süß used did not. Given the fact that Oberauer and Süß found no difference between simple and complex spans, it would appear to be impossible to draw any conclusions about interference effects from their data. In contrast, the preceding results provide converging evidence for Jenkins, Myerson, et al.'s (1999) contention that the effects of secondary spatial tasks on spatial memory spans are larger for individuals with larger spans than they are for individuals with smaller spans.

Implications for Theories of Working Memory

Oberauer and Süß (2000) questioned not just the validity of the findings reported by Jenkins, Myerson, et al. (1999), but also the relevance of these findings for theories of working memory. Oberauer and Süß argued that the relation between interference effect size and simple span is irrelevant to working memory theories because simple and complex memory span tasks do not measure the same constructs. It is only complex span, they claimed, that is of concern to theories that emphasize the role of interference and inhibition in working memory, because "of course, it is only the complex span, not the simple span variant, in which the issue of inhibiting irrelevant information arises at all" (p. 731). According to Oberauer and Süß, only complex span tasks require that memory representations be suppressed when no longer necessary. It is for this reason, they argued, that working memory theories that emphasize the role of interference and inhibition do not predict that a person's simple span will be related to his or her susceptibility to interference.

We certainly would agree that if simple span tasks did not require inhibition, then a working memory theory emphasizing differences in inhibitory ability would not predict that people with larger spans are less susceptible to interference. However, many researchers, including some whose theoretical framework emphasizes the role of inhibition in working memory, would argue that simple span tasks *do* require inhibition. May, Hasher, and Kane (1999), for example, recently pointed out that span

tasks, because they involve repeated trials, require people to suppress items from previous lists. They argued that, as a consequence, proactive interference should be particularly noticeable in people who have a reduced ability to inhibit no-longer-relevant information. Thus, in their view, the very nature of span measures (including both simple and complex spans) means such measures will reflect inhibitory ability and not just capacity.

This view is also widely held in neuropsychology. For example, Berg (1997), in his chapter on screening tests in *The Neuropsychology Handbook* (Horton, Wedding, & Webster, 1997), categorized the WAIS forward digit span task (Wechsler, 1981) as a test of attention because it involves both the maintenance of relevant information and the simultaneous suppression of irrelevant or no-longer-relevant information. Other researchers appear to be working from similar assumptions. For example, Jonides and his colleagues (D'Esposito, Postle, Jonides, & Smith, 1999; Jonides, Smith, Marshuetz, Koeppel, & Reuter-Lorenz 1998) have used simple short-term memory tasks to identify neural structures involved in suppressing no-longer-relevant information precisely because they believe that inhibition on such tasks is relevant to working memory performance.

Thus, we are not alone in arguing that, although simple span tasks may place less demand on inhibitory abilities than complex span tasks, they clearly require participants to ignore irrelevant information, most noticeably that from previous trials but perhaps information from other events, both external and internal, as well. Moreover, because inhibition theorists have not advocated the use of relative measures, the implication (by default) is that interference should be measured in absolute terms. Accordingly, an inhibition-based theory of individual differences should predict that those with less susceptibility to interference will tend to have higher simple spans and will suffer less interference on complex spans. Notably, the present data revealed the opposite pattern: Specifically, the absolute amount of interference produced by secondary tasks was larger for those with higher simple spans than for those with lower simple spans.

Interestingly, the effects of other manipulations that interfere with memory span also vary with simple span size. Logie et al. (1996) examined the relationship between verbal memory span and the size of phonological similarity and word length effects. Importantly, the conditions that Logie et al. used to measure the effect sizes were not the same as the conditions they used to measure the memory spans in order to avoid the possibility of regression to the mean. Their findings were similar to the present results in that individuals with larger simple spans showed larger effects.

May et al. (1999) pointed to the phonological similarity effect as evidence that interference, in this case interference between similar items, plays a role in memory span tasks, and Nairne, Neath, and Serra (1997) have suggested that proactive interference may underlie the word length effect. Logie et al. (1996) suggested that the extent of both effects was determined by two factors.

One of these was a tendency for individuals with larger spans to use different strategies than individuals with smaller spans, strategies that make them more vulnerable to various manipulations that decrease span. In addition to the effect of strategy choice, however, they noted that there is also an independent effect of memory span. This effect is captured by the stock market analogy presented earlier and does not depend on assumptions regarding either inhibition or strategies: Manipulations that decrease span simply may affect the representations of all items in working memory with approximately equal probability, so that the more items that are represented, the greater the number of items that will be lost.

Jenkins, Myerson, et al. (1999) were concerned, of course, not just with individual differences in susceptibility to interference, but also with age differences in susceptibility to interference and how individual differences interact with age differences. The results of the Logie et al. (1996) study and those of Jenkins and her colleagues (Jenkins et al., 1998; Jenkins, Myerson, & Hale, 1999; Jenkins, Myerson, et al., 1999) shed new light on these interactions. For example, the participants in Experiment 1 of the Logie et al. study ranged in age from 18 to 70 years, but there was no relationship between age and the relative size of phonological similarity and word-length effects (i.e., effect size expressed as a percentage of simple word span). This suggests that, regardless of their age, individuals with the same simple span tended to show the same effect size.

Age differences in the size of interference effects in the present study (Jenkins et al., 1998; Jenkins, Myerson, & Hale, 1999) also appear to be attributable to age differences in simple span. As noted above, there were no significant differences between the regression parameters for young and older adults. The implications of this finding are highlighted in comparisons of lower and higher span subgroups. For example, consider the lower span young adults and the higher span older adults. Based on their first assessment, these subgroups did not differ in their simple spans (mean spans = 5.8 and 5.7 items, respectively), and accordingly there were no significant differences between the two subgroups in their single- and double-touch interference effects.

In contrast, the interference effects for the higher span young group were approximately twice those for the lower span old group, groups whose simple spans also turned out to differ by a factor of approximately two (mean spans = 8.1 and 4.2 items, respectively). This result, depicted in Figure 2, is exactly the opposite of what might have been expected if higher span individuals had a greater ability to inhibit irrelevant information and older adults had an inhibition deficit, but it is obviously consistent with the idea that, regardless of age, the amount of interference produced by secondary tasks increases as simple span increases.

Conclusions

Oberauer and Süß (2000) challenged Jenkins, Myerson, et al.'s (1999) report of a relationship between indi-

Figure 2. Interference effects for higher span young adults and lower span older adults.

vidual differences in simple memory span and the amount of interference produced by a secondary task, claiming that this relationship was an artifact produced by regression to the mean. Although regression to the mean may have played a role in the Jenkins, Myerson, et al. findings, as Jenkins and her colleagues acknowledged in their original report, the data and analyses presented here demonstrate that their conclusion was correct: Individuals who have lower memory spans in the absence of a secondary task tend to be more affected (i.e., they show a larger decrease in span) by the addition of a secondary task than those with higher spans. The present results demonstrate further that, at least with the procedures used by Jenkins and her colleagues, there are no age differences in interference effects beyond those attributable to differences in simple memory span. Although the present analyses were confined to spatial memory span tasks and spatial secondary tasks, similar findings have been reported in the verbal domain (Logie et al., 1996).

The mechanisms underlying the observed relationship between interference effect size and simple span as well as the lack of age difference in interference effects when simple span is equivalent may ultimately prove to have nothing to do with individual and age differences in inhibitory ability. As suggested previously, for example, manipulations that decrease span may affect the representations of all items in working memory with approximately equal probability, so that the more items that are represented, the greater the number of items that will be lost. If this interpretation is correct, then in one sense, individuals with larger spans are not *more susceptible* to interference than those with smaller spans, they are just *more affected* by interference. That is, if the number of items being lost is the measure of susceptibility to interference, then susceptibility increases with span. If the probability of an item being lost from working memory

is the measure of susceptibility to interference, however, then susceptibility is independent of span.

This interpretation of interference effects may help resolve the apparent conflict between an inhibition-based theoretical framework and the observed relation between span and the size of interference effects. It does so, of course, by assuming that the absolute size of interference effects does not measure inhibitory ability, but this does not make the present findings irrelevant to theories of working memory (cf. Oberauer & Süß, 2000). Even if one believes that inhibition plays an important role in working memory, it would not seem to follow that only phenomena that directly reflect inhibition are relevant. To the extent that working memory theories purport to be theories of the whole working memory system, we believe that they will have to accommodate the present results and other, similar findings (e.g., Logie et al., 1996), whatever the underlying mechanisms turn out to be.

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NOTE

1. In the present case, given that the error in X is the same for all three regression slopes, and thus all three slopes are attenuated to the

same degree (relative to the slopes of the corresponding true, functional relations), it is possible to estimate the true slope of the relation between complex and simple span for each complex span condition. Because the same attenuation factor, a , operates in all three cases, the ratio of two observed slopes (that of the regression of complex span on simple span and that of simple span on simple span) equals the ratio of the corresponding true slopes ($\beta/\beta' = ab/ab' = b/b'$). Further, because the true slope, b' , of the relation between the two assessments of simple span equals 1.0, it follows that $b = \beta/\beta'$, that is, the ratio of the observed slopes provides an estimate of the true slope of the relation between complex and simple span. The size of the true interference effect is estimated to be 1.0 minus the estimate of the true slope.

Using this estimator, the true slope of the relation between complex span and simple span when the secondary task is single-touch is estimated to be 0.708, and the true slope of the relation between complex span and simple span when the secondary task is double-touch is estimated to be 0.457. To put this in more concrete terms, these results suggest that across individuals the amount of interference produced by the double-touch secondary task, for example, grows by approximately half an item for each item that an individual can remember when there is no secondary task.

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