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Responses contribute to context effects on ratio-setting timing tasks

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Abstract. Short durations in a range of standard durations are typically overreproduced and long durations underreproduced ('Vierordt's Law'). This contextual distortion may result from each trial assimilating the central tendency of the preceding series. We examine whether responses as well as standard durations contribute to this distortion. Two experiments using nonequal-setting ratio tasks are described. On equal-setting ratio tasks the means of the standards and responses are nearly equal, but in half-setting and double-setting standards and responses differ. In both experiments a central tendency of standards plus responses better predicted the indifference interval than did the mean of the standards alone. The coefficients of variation were larger for all double-setting conditions than for half-setting at the same response durations, suggesting pooling of the trial variance with the central tendency's variance. Longer equal-setting reproductions were generated by randomly intermixing equal-setting with double-setting than by intermixing with half-setting. Thus, assimilation of a central tendency that includes both standards and responses can account for the location of the indifference intervals ('Vierordt's Law'), for the response variation and for the additive effect we observed where two entire response curves (for equal-setting) were shifted relative to each other by the influence of nonequal-setting trials.

Keywords: time perception, context, Vierordt's Law, timing, temporal reproduction, ratio task

1 Introduction

Context affects performance on many cognitive and perceptual tasks (eg Hellström 1985; Helson 1964; Parducci 1968; Tversky and Kahneman 1974). A common effect is that response magnitudes at the bottom of the range of stimulus intensities increase whereas response magnitudes at the top of the range decrease. This phenomenon was first reported by Vierordt (1868) (Lejeune and Wearden 2009) and reported later by others (eg Bobko et al 1977; Jazayeri and Shadlen 2010; Noulhiane et al 2009). One explanation is that the central tendency of recently experienced stimuli is assimilated by the current stimulus; thus, performance on the current trial is based on a weighted average of the current stimulus and the central tendency. This explanation was proposed as early as 1910 by Hollingworth and formalized into an extensive theory by Helson (1964). Stevens and Greenbaum (1966) recognized that assimilation of the central tendency (what they called regression to the mean) was a potentially significant distortion that might limit the interpretation of psychophysical judgments. They argued that regression effects may be small in noise-free environments and large when "judgments are subject to perturbations" (page 439). Similarly, Huttenlocher and colleagues (2000) proposed that general knowledge (the context or a priori knowledge) may be incorporated into the mental representation of the current stimulus because the recent context is a useful predictor of forthcoming stimuli. In the presence of uncertainty about the current stimulus, adding general knowledge should improve performance on the trial.

One problem, though, is that what comprises the contextual effects may depend on circumstances. The central tendency of recently experienced durations is only one of many possible contextual effects, including range, spacing, pattern, sequential order effects, and expectancy. Sailor and Antoine (2005), for instance, have recently noted: "A considerable challenge for accounts of assimilation effects has been to explain which stimuli are 'contextually relevant' "(page 849).

We have lately demonstrated that the central tendency of recently experienced durations affected performance on a temporal reproduction task (Ryan 2011). We presented groups of participants with distributions of standard durations that covered the same range of durations, had the same spacing between adjacent standard durations, and had the same total number of trials but differed in the density of the presented durations. Reproductions by the group presented with a distribution of standard durations skewed towards shorter durations were shorter than those in the group presented with a flat distribution. Reproductions on the skewed long distribution were longer than on the flat distribution. These results were modeled with the reproductions being a weighted average of the current trial's standard duration and the central tendency of the distribution, along the lines of Helson's (1964) adaptation theory and Hellström's (1985) model of the time order error.

The central tendency may nominally be defined as the (geometric or arithmetic) mean of the standard durations that are presented to the participant (as in Ryan 2011 for duration stimuli or as in Riskey et al 1979, and Schifferstein 1995 for taste stimuli). Use of the arithmetic mean is appropriate if a linear relationship between objective and subjective time exists. Although there has been debate on this point, many studies support a linear relationship (see for reviews and comments Allan 1979; Eisler 1975; Grondin 2001; Staddon and Higa 1999). In our previous study (Ryan 2011) we used the arithmetic mean of recent durations as our measure of the central tendency. This nominal central tendency ignored the influence of experienced reproduced durations.

However, on a reproduction task participants clearly experience their own reproductions, and these may contribute to the central tendency of recently experienced durations. Defining what stimuli are 'contextually relevant' and which values should contribute to the central tendency is obviously important. On equal-setting temporal reproduction tasks the function relating reproductions to standard durations has a slope approaching 1. Eisler (1975), reviewing many studies, showed typical slopes between 0.9 and 1. With nearly veridical performance, reproductions—even if they contribute to the central tendency of recently experienced durations—should have little detectable effect in addition to the context defined by the standard durations. Although Vierordt's phenomenon (Lejeune and Wearden 2009; Vierordt 1868) suggests that reproductions of short durations show positive constant errors whereas longer durations show negative constant errors, these systematic variations from veridical performance may come close to averaging out and the central tendency of the reproductions should closely resemble the central tendency of the standard durations.

Though it is a reasonable expectation that the reproductions as well as the standard durations contribute to the context that influences current performance, they may not. For instance, in some models of timing processes the mental representations of the standard and the reproduction are thought to differ. Most timing models place the representation of the standard duration into a reference memory to be compared against working memory which holds the reproduced duration as it is being generated (eg Gibbon and Church 1990; Staddon and Higa 1999). Is a reference memory more likely to contribute to the central tendency than the contents of working memory? Second, as Zakay (1990) notes, perception of the standard is relatively passive as compared with the active production of the reproduced duration. Either of these factors might limit (or enhance) the contribution of the reproductions to the central tendency of the recently experienced durations. Though we suspect that response durations contribute to the central tendency, we are unaware of any experiments that directly test this hypothesis. We do so in these experiments.

2 Experiment 1

Ratio-setting tasks have been used largely to characterize the exponents of psychophysical functions (eg Allan 1978; Eisler 1975). They also, however, provide a means for manipulating the value of responses independently of the value of standards. For a given set of standard durations, if responses contribute to context effects, double-setting will produce a different context than half-setting. The combined standard plus response central tendency should be reflected experimentally in a different indifference interval (point of accurate performance) for half-setting than for double-setting.

In this experiment we adopt a new procedure that enhances the Vierordt effect. When participants were asked to respond with two consecutive discrete equal-setting reproductions in response to the presentation of a single standard duration, the second reproduction showed greater elevation of reproduced duration at short durations and greater reduction in reproduced duration at longer durations without a change in the indifference interval (Ryan 2012). We interpreted this finding as resulting from greater uncertainty about the standard duration when participants perform the more temporally remote second reproduction. Uncertainty has been predicted to increase a person's reliance on general information (the context or recent central tendency) at the expense of specific trial information (Huttenlocher et al 2000).

If, in fact, any distortions we observe on half-setting and double-setting tasks are due to assimilation of the central tendency, then we should also observe greater distortions of responses of the second of two consecutive responses, just as we observed with equal-setting.

2.1 *Materials and methods*

2.1.1 *Participants.* In experiment 1, female ($n = 15$) and male ($n = 10$) undergraduate students enrolled in psychology courses volunteered to participate in these experiments and received extra credit as a result of their participation. Conditions of participation were approved by the Oregon State University (OSU) Institutional Review Board and met all current ethical guidelines for the use of human participants.

2.1.2 *Procedures.* The experiments were conducted using Windows-based computers. To enable real-time operations, the experiments were programmed with the Tscope toolkit (Stevens et al 2006). Each experiment was conducted in a single session lasting less than 30 min. Participants received instructions and an opportunity to practice the timing task during the introductory screens of the computer program. They initiated a series of self-paced trials of a reproduction timing task. Both the onset of each trial and the onset of the reproduction were under the control of the participants to ensue that attention was focused on the task at least at the onset of the standard and the reproductions. The to-be-timed intervals were specified by a continuous visual display that consisted of a red 33 × 37 mm rectangle centered on the screen against a black background. A white command line occupied the top 10 mm of the screen. This display remained on the screen for one of ten durations: 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, or 5.5 s that were presented 10 times each in random order. Participants were asked, both at the initial verbal briefing and again on the written computerized instructions, to judge the duration that this standard display remained on the screen without mentally counting. No other attempt was made to prevent counting, but participants were asked at debriefing about their performance of the task. There were no self-reports of counting. We have previously shown that these instructions are effective in preventing timing by counting (Ryan et al 2004). After timing the duration of the standard interval, participants were to reproduce this interval by initiating a new display, identical to the standard interval display except that it was yellow–brown, and to terminate the display with a second keystroke. Participants were informed at the start of the experiment whether they would be doing half-setting ($n = 13$) or double-setting ($n = 12$). And, on every trial, the word 'half' or 'twice' was written in white lettering within the standard duration display red rectangle. They were asked to reproduce the standard in the same way a second time after they completed their first response.

2.1.3 *Statistical analysis.* Because these were ratio-setting tasks, the ratio of each reproduction to the standard duration was the primary measure. To determine differences between first and second reproduction, analyses of variance were performed with duration of the standards and reproduction number as repeated measures and setting type (half versus double) as a between-subjects variable. To examine variability, the coefficient of variation (CV) was calculated for each subject for each standard duration as the standard deviation for that response divided by the mean response (in seconds). Indifference intervals can be defined as the transition point between positive constant errors and negative constant errors. They were estimated by examination of the response duration to targeted duration function (figure 1b), finding the last positive error and first negative error, and interpolating the standard duration value for the transition.

2.2 *Results*

2.2.1 *First versus second reproductions.* As can be seen in figure 1a, response durations as ratios of the standards vary with duration. For double-setting, responses are relatively longer at short durations and shorter at long durations. For half-setting, the longer responses are seen at shorter standards. These effects were greater for the second reproduction, as compared with the first, for both the double-setting and half-setting tasks. These changes in the shape of the response to standard durations curves are significant, as shown by significant interactions between duration and reproduction number ($F_{9,207} = 2.533, p = 0.009, \eta_p^2 = 0.073$) and between duration, reproduction number, and response type ($F_{9,207} = 9.279, p < 0.001, \eta_p^2 = 0.267$).

To visualize the indifference intervals more easily, in figure 1b we recalculate the ratios and replot these responses relative to the targeted durations (eg a 3 s standard gives a target of 1.5 s for half-setting and 6 s for double-setting). A ratio of response to target of 1 equals accurate performance (the indifference interval). For double-setting, the indifference interval is between 5 s and 6 s of the targeted durations for both the first and second reproductions. For half-setting, the indifference interval is at the top of the range of targeted durations, near 2.5 s. For a more traditional view, we also replot the data on log–log axes in figure 1c. As can be seen, the slope of the second response is slightly different from that of the first.

2.2.2 *Coefficient of variation.* The CV shows greater relative variability at shorter durations than longer durations. There is a significant effect of standard duration ($F_{9,207} = 8.886$, $p < 0.001$, $\eta_p^2 = 0.247$) and standard duration by response type ($F_{9,207} = 4.10$, $p < 0.001$, $\eta_p^2 = 0.114$). The CVs do not differ between the first and second responses, as shown by a nonsignificant interaction between standard duration, response type, and response number ($F_{9,207} = 0.728$, $p = 0.59$, $\eta_p^2 = 0.029$). The problem with this analysis is that, although the same standard durations were presented to both groups, the targeted durations differed. Because the CV changes with duration, the shorter responses of the half-setting group should have larger CVs than the longer responses of the double-setting group, accounting for the observed interaction between standard duration and response type. A more meaningful comparison is between CVs at the same response duration. The two groups share only one targeted duration, at 2 s (from the 4 s standard for the half-setting group and the 1 s standard for the double-setting group). A *t*-test shows that the CVs differ between groups at this targeted duration ($t_{23} = 4.15$, $p < 0.001$). Because the response durations may not match the targeted durations, we plotted the CV as a function of the mean response duration in figure 2. For the same response durations, the double-setting group is more variable than the half-setting group. The first and second responses do not differ.

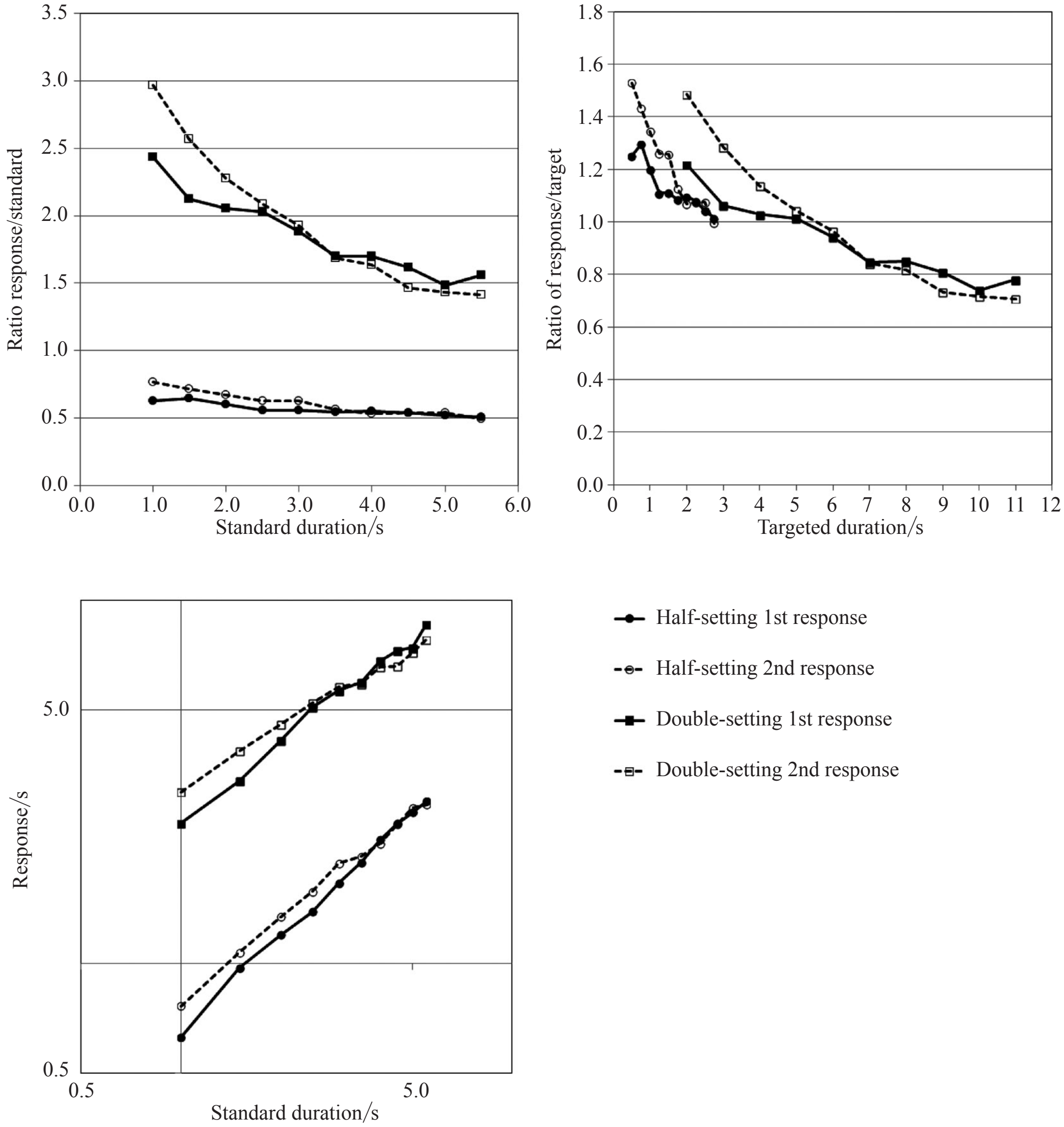

Figure 1. The mean ratio of the response duration to the standard duration is plotted for half-setting and double-setting groups, for both of the two consecutive responses that followed a single presentation of the standard (1a). The overresponse to short durations and underresponse to long durations characteristic of Vierordt's Law can be seen. To locate the indifference interval (point of accurate performance), the data are replotted relative to the targeted response duration. A ratio of 1 indicates accurate performance (1b). A third view of these data is shown as the actual response duration plotted relative to the standard duration on log–log axes (1c).

2.3 *Discussion*

This experiment demonstrates that ratio-setting tasks other than equal-setting are subject to the distortions that are characterized by Vierordt's Law. The second response of the pair of half-setting or double-setting responses shows more distortion of the response curve than that for the first reproduction. This is the same distortion that we previously reported on an equal-setting reproduction task (Ryan 2012). This distortion cannot be explained either by the establishment of a response bias or by sequential order effects. A response bias (longer for double-setting, shorter for half-setting) cannot explain the decline in relative response magnitudes as the standard duration increases. Similarly, sequential order effects (the response on the current trial is influenced by the magnitude of the preceding trial) have been observed in

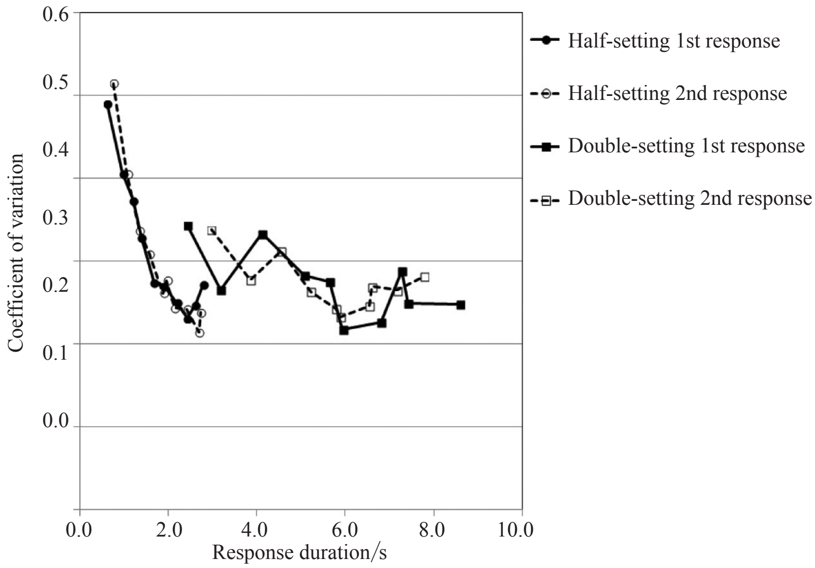

Figure 2. Response variability (the coefficient of variation) is plotted versus the response duration. Note that variability is greater for double-setting than for half-setting at comparable response durations.

some contexts (Cross 1973) and could explain Vierordt's Law. With random presentation of the standards, trials with long standards are more likely to follow trials with shorter ones and short ones are more likely to follow longer ones. However, sequential order effects cannot easily explain why the second of two consecutive responses is more distorted than the first. The difference in magnitude of the first and second responses is much smaller than the average difference between the current trial and the preceding trial.

The difference between first and second responses can be explained by assimilation of the central tendency. We have previously demonstrated that, with equal setting, changing the central tendency by manipulating the distribution of standard durations predictably alters response magnitudes and have argued that Vierordt's Law may be explained by assimilation of the central tendency (Ryan 2011). Our previous demonstration of this distortion with two consecutive responses on an equal-setting task (Ryan 2012) was interpreted as resulting from uncertainty. As the second reproduction is more remote from the standard than is the first, the memory representation of the standard may become less reliable. Huttenlocher and colleagues (2000) have argued that perceptual systems attempt to correct for partial or uncertain information by biasing current perception by including general (prior) knowledge. The more uncertain, the greater the weighting of the general information. Such a correction mechanism might well be adaptive, especially in the face of noise, distraction, or otherwise unreliable trial information (Stevens and Greenbaum 1966). Thus, if the second response is more heavily weighted towards the central tendency, the second response should show a steeper response to standard curve, but with the same indifference interval. The data shown in figure 1 confirm this prediction.

Do response durations contribute to the central tendency? The central tendency assimilation hypothesis suggests that the indifference interval (the point of accurate performance) should be near the central tendency. We approximated the central tendency from figure 1 and compare them in table 1 with possible central tendencies. In the current experiment the half-setting and double-setting groups were presented with the same set of standard durations. As can be seen in table 1, if only the standards contributed to the central tendency (as the arithmetic mean), it would be 3.25 s for both groups. If both responses are also included, the central tendency for the half-setting group would be 2.30 s. The observed indifference interval for half-setting falls between these values. For the double-setting group the combined central tendency would be 4.84 s, which is much closer to the observed value than is the standard only central tendency (table 1). The geometric means are poorer predictors than the arithmetic means for the double-setting group.

Table 1. Estimated indifference intervals for the first response based on figure 1b, possible central tendencies, and their differences for experiment 1.

Group	Half-setting	Difference	Double-setting	Difference
Approximate indifference interval	2.75 s		5.1 s	
Arithmetic mean				
standards only	3.25	0.50	3.25	−1.85
standards plus responses	2.30	−0.45	4.84	−0.26
Geometric mean				
standards only	2.88	0.13	2.88	−2.22
standards plus responses	2.01	−0.74	4.36	−0.74

Prior studies of double-setting have also shown greater doubling at short durations than at longer durations within the presented range. Marum's (1968) (calculated from data in table 2) participants showed mean double-setting ratios of 2.16 at the 2 s standard duration, 2.18 at 4 s, and 1.74 or less above 8 s. Chatterjea (1964) reported overestimation at 2 s and underestimations at 4 s and longer standards. Eisler (1975) (calculated from data in table 2) reported double-setting ratios of 1.89 and 1.83 at 1.3 and 1.8 s standards, respectively, and 1.75 and 1.54 at 4.5 and 6 s standards, respectively. Allan's (1978) (calculated from data in table 1) 4 participants (who performed 108 trials at each standard duration) produced double-setting ratios that declined from 2.01 at 0.5 s to 1.54 at 2.25 s. Chatterjea (1964) suggested that the decline in response magnitudes at longer durations was the result of boredom. Marum (1968) rejected that explanation as he reported the same effect in normal as compared with sensory isolation conditions. The latter condition, he argued, is by its nature excessively boring. Instead, he argued that the decline is due to attentional failures. The other authors did not attempt to explain these declines in double-setting reproduction ratios. Neither the boredom nor attentional explanations can explain the greater effect on the second of two consecutive responses. Our explanation for these declines is the central tendency assimilation hypothesis, as it predicts the response patterns that are observed.

The CVs between the half-setting and double-setting groups differed. As seen in figure 2, the CVs of half-setting responses between 1.75 and 2.5 s are smaller than for double-setting responses between about 2.5 and 5.5 s. In this experiment there are three possible origins of the variation contributing to the CV. First, the CV might reflect only the variation of the mental representation of the standard duration. If so, for a given standard half-setting and double-setting responses should be equally variable. This would mean that for a given response or target duration the variation should be larger for half-setting than for double-setting. This is the opposite from what we observed. Second, the response variation might reflect only the variation of the mental representation of the targeted durations. If this were correct, the CV should not differ between groups for a given response duration, which is also not the result we observed.

A third possibility is that if assimilation of the central tendency occurs, the variance of the central tendency might be pooled with the variance of the current standard duration. Because the variance (or standard deviation) grows with duration, the larger central tendency of the double-setting groups would contribute more variance to the pooled estimate than the central tendency of the half-setting group. For a given response duration the pooled variance should be larger for the double-setting group than for the half-setting group. This is the pattern we observed. This third possibility has the virtue of parsimony as only one mechanism (assimilation) is needed to explain the shifts in indifference intervals and the differences in CV.

In our previous studies with repeated responses on an equal-setting task (Ryan 2012) we observed reduced response variability with a blocked presentation (3 strings of ten reproductions all at the same standard duration) as opposed to two reproductions of randomly presented standards and argued that the reduced variability reflected more certainty of the targeted duration from one response to the next in the blocked design. We observed a weak tendency for the CV to be larger for the second of the two consecutive reproductions, but this difference was not significant. We also do not see a significant difference in the CV between first and second responses for either half-setting or double-setting. Because we argue that the greater apparent assimilation of the central tendency by the second response reflects greater uncertainty about the standard, one might therefore expect the CVs to differ. Because we used random presentation of standards, the trial-to-trial uncertainty may be much greater than difference between the first versus second responses, masking any effect. And, if our speculation about pooling standard duration and central tendency variabilities is correct, the central tendency variability may also have a masking effect.

3 Experiment 2

The results of experiment 1 suggested that assimilation of the central tendency contributes to the Vierordt's Law-like distortions seen with both half-setting and double-setting. The results also showed that the indifference interval more closely resembled a central tendency composed of both the standard durations and the response durations than it did a central tendency reflecting only the standards.

In this experiment we adopt another strategy to determine if participants' responses influence temporal context. Two groups of participants were asked to do a reproduction task. On half of the trials participants performed a typical temporal reproduction task by reproducing an interval that was equal in length to the standard (equal-setting). On the other half of the trials one group performed a half-setting task (HE group). These two types of trials were randomly intermixed. The second group performed equal-setting and double-setting (DE group). If the central tendency is defined solely by the serial average of the standard durations, the participants' performance on the equal-setting trials should be the same for both groups. If, however, the responses contribute to the central tendency, the participants' performance on the equal-setting trials should differ, being longer for the double-setting group.

3.1 *Materials and methods*

3.1.1 *Participants.* Female ($n = 11$) and male ($n = 8$) undergraduate students enrolled in psychology courses volunteered to participate in these experiments and received extra credit as a result of their participation. Conditions of participation were approved by the OSU Institutional Review Board and met all current ethical guidelines for the use of human participants.

3.1.2 *Procedures.* The experiments were conducted as in experiment 1. For the HE group ($n = 9$, five females, four males), either the word "half" or "same" was written in white lettering within the standard duration display as an instruction for the type of response to be made on that trial. For the other group of participants ($n = 10$, six females, four males) the display contained the either the word "twice" or "same". Participants performed 8 trials of each type at each of ten standard durations: 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, or 5.5 s.

3.1.3 *Statistical analysis.* As these were ratio-setting tasks, the best performance measure was the ratio of the reproduction to the standard duration. To determine effects of the manipulations, analyses of variance were performed with duration of the standards as a repeated measure and setting type (half versus double) as a between-subjects variable. The CV was also examined separately for the equal-setting and nonequal-setting conditions. The indifference interval was estimated by examination of the response duration to targeted duration function and interpolating the standard duration value for the ratio of 1.

3.2 *Results of experiment 2*

3.2.1 *Half-setting and double-setting reproductions.* The trial-by-trial instructions to perform half-setting, equal-setting, or double-setting were successful. As seen in figure 3, the double-setting instruction produced response ratios ranging from 2.28 to 1.42, declining with increasing standard durations (main effect of duration: $F_{9,81} = 10.441$, $p < 0.001$, $\eta_p^2 = 0.573$). Half-setting instructions led to response ratios ranging from 0.489 to 0.634, but with relative constant performance across standard durations (main effect of duration: $F_{9,72} = 1.115$, $p = 0.364$, $\eta_p^2 = 0.123$).

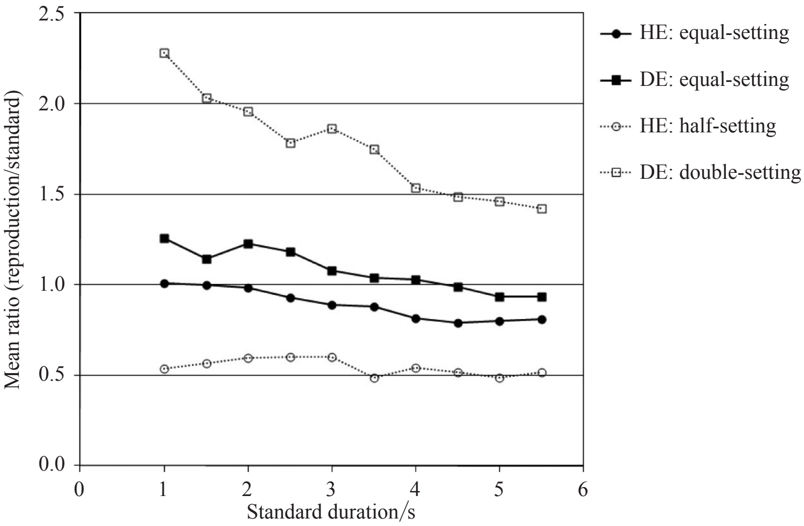

Figure 3. The mean ratio of the reproduced durations to standard durations is plotted versus the standard durations. One group of participants performed randomly intermixed double-setting (DE) and equal-setting (DE) trials. The other group performed randomly intermixed half-setting (HE) and equal-setting (HE) trials. The presence of nonequal-setting trials altered performance on the equal-setting trials.

3.2.2 *Equal-setting reproductions.* The equal-setting reproductions were influenced by the context in which they were performed (figure 3). For both groups of participants there was a decline in equal-setting reproductions with increasing standard durations (main effect of duration: double-setting group, $F_{9,81} = 5.187$, $p < 0.001$, $\eta_p^2 = 0.366$; half-setting group, $F_{9,72} = 3.521$, $p < 0.001$, $\eta_p^2 = 0.306$). The participants who engaged in double-setting (DE group) on half of the trials produced significantly longer equal-setting reproductions than did those in the HE group who engaged in half-setting (main effect of setting type: $F_{1,17} = 6.453$, $p < 0.001$, $\eta_p^2 = 0.275$). The shape of the equal-setting reproduction ratio to standard durations curves did not differ (interaction between setting type and duration: $F_{9,153} = 0.367$, p=0.949, $\eta_p^2 = 0.014$).

3.2.3 *Sequential order effects.* Because equal-setting trials were randomly intermixed with either half-setting or double-setting trials, the difference between HE and DE groups on equal-setting might be due to sequential-order effects caused by the setting type of the previous trial rather than central tendency effects. To examine this possibility, equal-setting trials were separated into two groups: those preceded by an equal-setting trial and those preceded by either a half-setting or double-setting trial. As can be seen in figure 4, equal-setting performance did not differ based on the nature of the preceding trial. The main effect of the prior trial setting type was nonsignificant ($F_{1,17} = 0.004$, $p = 0.951$, $\eta_p^2 = 0.0002$), as were all of the higher-order interactions.

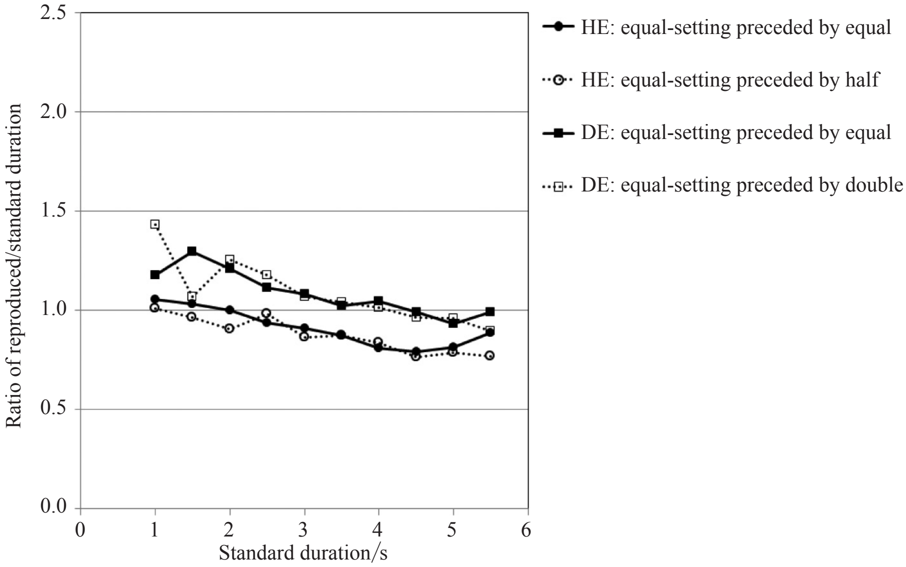

Figure 4. Equal-setting trials are plotted based on whether the preceding trial was an equal-setting trial or either a double-setting (DE group) or equal-setting (HE group) trial. The prior trial type does not predict performance, indicating that the differences between DE and HE groups does not result from a sequential-order effect.

3.2.4 *Coefficients of variation.* As in experiment 1, the half-setting condition and the double-setting condition shared only 1 targeted duration at 2 s. A *t*-test shows that the CVs differ between groups at this targeted duration ($t_{17} = 4.65$, $p < 0.001$), with a larger CV seen in the double-setting group. The CVs plotted against response durations are shown in figure 5 and reveal the same pattern for the half-setting and double-setting responses as seen in experiment 1.

The CVs of the equal-setting responses for the two groups can be directly compared as the participants were presented with the same set of standard durations. The difference between the HE and DE groups approaches significance (main effect of group: $F_{1,17} = 4.042$, p=0.061, $\eta_p^2 = 0.192$), with equal-setting responses in the DE group being more variable than those of the HE groups.

3.3 *Discussion*

The results of this experiment confirm our hypothesis that the responses a participant produces influence subsequent performance. As predicted, equal-setting responses were larger when randomly intermixed with double-setting (DE group) than when intermixed with half-setting (HE group). One explanation for this effect is that the response durations contribute, along with the standard durations, to the central tendency of recently experienced times. An alternative explanation, that intermixing equal-setting and nonequal-setting tasks leads to sequential-order effects (Cross 1973), was not confirmed by the data.

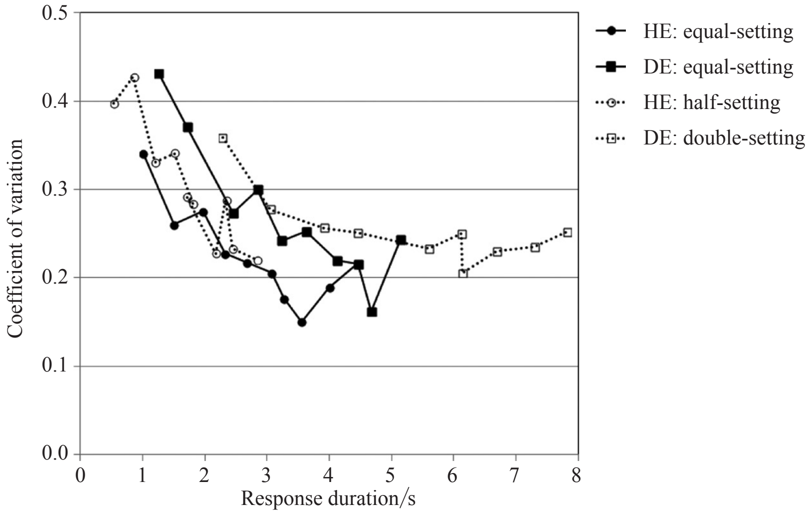

Figure 5. The coefficients of variation (CVs) for the groups in experiment 2 are plotted relative to the response duration. As in experiment 1, CVs are larger for double-setting than for half-setting at comparable response durations. The variability of the equal-setting trials also differed, being larger for the DE than HE group.

In the current experiment the distributions of standard durations are identical, but the central tendencies of the experienced responses differ between the half-setting and double-setting groups. The central tendency assimilation hypothesis suggests that the indifference interval (the point of accurate performance) should be near the central tendency. This is true for all four curves shown in figure 3. As shown in table 2, if the central tendency included only standards, the arithmetic mean would be 3.25 s and all four groups should show the same indifference interval. This is not the case. If responses are included in the central tendency, the central tendency for the HE group may be composed of three elements: the standard durations (weighted twice, as they were presented on both equal-setting and half-setting trials), the equal-setting responses, and the half-setting responses. The final arithmetic mean of these elements is 2.75 s. Similarly, for the DE group the weighted mean of the standard durations, the equal-setting reproductions, and the double-setting responses is 3.80 s. As can be seen in table 2, the observed indifference intervals are closer to the central tendencies that include both the standards and the responses. The indifference interval in the equal-setting condition for the HE group is hard to determine graphically (figure 3) because performance is nearly accurate between 1.75 and 2.75 s without ever becoming a negative constant error.

Table 2. The estimated indifference intervals, based on targeted durations, possible central tendencies, and their differences for experiment 2.

Group	HE	Difference		DE	Difference	
		equal	half		equal	double
Approximate indifference intervals						
equal/s	1.5			4.4		
half/s	2.8					
Double/s				3.5		
Arithmetic mean						
standards only	3.25	1.75	0.45	3.25	−1.15	0.25
standards plus responses	2.75	1.25	0.05	3.80	−0.60	−0.20

We estimated the indifference intervals as being just above the highest tested targeted duration. As an alternative, we also calculated a second-order polynomial to fit the curve and found a slightly shorter indifference interval of 2.6 s.

These results support the finding from experiment 1 that the CVs are larger for double-setting than for half-setting for the same response durations. The difference here approaches significance ($p = 0.061$) and essentially replicates the previous finding. This experiment adds an additional observation: equal-setting responses are more variable, for the same response durations, when intermixed with double-setting than when intermixed with half-setting trials. This is the result that would be predicted from our speculation that the variability of the central tendency is pooled with the variability of each standard duration.

4 Overall discussion

Both experiments demonstrated distortions of the response to standard duration curves in the manner described by Vierordt (Lejeune and Wearden 2009; Vierordt 1868) for half-setting and double-setting tasks as well as for equal-setting. These distortions appear to result from assimilation of the central tendency leading to overreproductions of the short-duration standards and underreproductions of the longer durations. Responses appear to be determined by a weighted mix of current trial information and more general information about the distribution of recently experienced durations. This intermixing may involve not just the durations but also the variabilities of the respective representations of the standards and the central tendency.

The results of these experiments were inconsistent with the hypotheses that this distortion was due to the development of a general response bias or due to sequential-order effects of having intermixed trials with different reproduction ratios.

These experiments support the hypothesis that the central tendency of recently experienced durations includes not only the standard durations but also the response durations. The effect of this on equal-setting tasks presented alone is minimal as compared with a central tendency defined by the standard durations. Reproductions are not entirely veridical, but the overreproductions at short durations of the range are more-or-less countered by the underreproductions at the longer intervals. However, intermixing equal-setting trials with half-setting or double-setting trials introduces an additional distortion. Adding the half-setting and double-setting responses to the central tendency shifted the value of the combined central tendency, which, in turn, clearly and substantially altered the magnitude of the intermixed equal-setting reproductions.

Thus, in these experiments we observed two types of distortions caused by assimilation of the central tendency. First is the Vierordt type of distortion (Lejeune and Wearden 2009; Vierordt 1868) in which short standard durations in the range are over reproduced whereas long durations are underreproduced. Second is an additive effect where two entire response curves, as shown by our two equal-setting groups, are shifted relative to each other because the groups experience different central tendencies.

Intermixing equal-setting and nonequal-setting trials is an unusual experimental procedure. Prior studies have used only one response ratio. In previous nonequal-setting experiments both the standards and the responses should have contributed to the central tendency. The influence of the standards on the central tendency should reduce the magnitude of the double-setting responses at every duration within the range and, conversely, should increase the half-setting responses throughout their range. Although distortions of ratio-setting tasks have been recognized (eg Blankenship and Anderson 1976; Stevens and Greenbaum 1966), this particular source of distortion has not.

It has been noted that nonequal-setting tasks produce different response exponents than do equal-setting tasks. For instance, Blankenship and Anderson (1976) argued that the mismatch in slopes between veridical performance and actual performance on nonequal-setting ratio tasks, and the different exponents they generated, is due to the subjective interpretation of the fraction or multiplier given for the task. That is, the instruction given (double or half) is not the value of the mathematical operation that the participants actually use. This idea does not explain our data or Vierordt's Law well, as it would require the subjective value of the multiplier to vary systematically with the standard durations and between the first and second responses. We suggest that the mismatch in exponents arises from inclusion of the responses into the context that influences performance. That is, because the central tendency appears to include both the standard duration and the responses, responses on ratio-settings other than for equal-setting should be systematically distorted because they differ from the standard durations. For double-setting the standards are shorter and should lead to shorter than targeted responses. Similarly, for half-setting the standards are longer and should lead to longer than targeted responses. Because of these distortions, the slope of the response to standard curves will shift. We see this shifting with the second as compared with the first response. Attempts to estimate exponents for power functions based on nonequal-setting ratio-setting data (eg Allan 1978; Blankenship and Anderson 1976; Eisler 1975) may be misleading.

The differences in CV we observed in experiments 1 and 2 between half-setting and double setting groups are incompatible with one current theory of timing. This timing model, Gibbon's Scalar Expectancy Theory (Gibbon and Church 1990), posits that timing variability reflects from fluctuations in the clock mechanism, the magnitude of the variability being a function of duration. That theory would predict that the CV should be the same across groups for the same response duration, as the variability in the clock should be the same for timing half-setting or double-setting responses. Our results suggest that variations in the timing mechanism (whether it is a clock, decay of memory traces, counts of the number of changes and events, chains of behaviors, or other mechanisms), though they might contribute to response variability, are not the sole source of variability.

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