Single-Modality Memory Mixing in Temporal Generalization
An Effect Due to Instructional Ambiguity
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Abstract
Two experiments investigated the effect of encoding two standard intervals on the performance in a temporal generalization task. Previous research has suggested that when individuals compare current time intervals with a standard encoded within both the auditory and the visual modality, they apparently use both the auditorily and the visually encoded standard for comparison so that each interval was compared with a “mixture” of both standard representations. However, the results of this study showed that memory mixing also happened within a pure visual modality. Moreover, it could be shown that the occurrence of memory mixing depended on instructional ambiguity. If in the training phase both standard durations were erroneously declared to be the same, memory mixing did occur in the testing phase. If, however, both standard durations were described as being different, memory mixing was not observed.

Key Words: temporal generalization, memory mixing, instructional ambiguity, visual modality, humans

Introduction
Scalar Expectancy Theory, or SET (Gibbon, 1991; Gibbon, Church, & Meck, 1984), developed to explain animal temporal behaviour, has become one of today’s most important theories about human timing. It describes the timing process as comprises three stages: the internal clock, temporal memory, and decision processes with which an individual relates a current time interval to a pre-given standard.

SET assumes that time is represented as a series of pulses regularly emitted by a pacemaker. The pulses are added and temporarily stored within an accumulator. The emission and accumulation of pulses start with the beginning of a to-be-timed signal and end with its cessation. The average value of the accumulated pulses is the product of the frequency of the pacemaker and the duration of the accumulation process.

SET postulates a memory system which is composed of a working memory and a long-term, or reference memory. Whereas working memory is supposed to store the output of the internal clock for the short term, e.g. for one trial, reference memory stores time intervals necessary for the whole task at hand. Representations of time are assumed to be transferred into reference memory by being multiplied with a memory storage constant, $k^*$, which varies as a Gaussian distribution with a mean of 1.0 (cf. Meck, 1983). Hence, after multiple presentations of durations which are important for later comparisons (usually declared as “standard durations” in experiments with humans) and thus are stored in reference memory, a Gaussian distribution of time intervals will be built up in reference memory.
When an individual wants to estimate the duration of a stimulus, he or she is supposed to compare the number of accumulated pulses, which represent the current stimulus duration and which are stored in short-term memory, with a sample of the standard duration stored in reference memory. Several rules on how to make this comparative judgment have been developed so far. Those rules in particular were recently applied which state that an individual judges two intervals to be equal if the difference between the encoded value of the current time interval, \( t \), and the remembered time interval, \( s \), divided by \( t \) (Wearden, 1992) or by \( s \) (Church & Gibbon, 1982), respectively, is smaller than a given decision threshold, \( b \).

In some cases, individuals are required to store a standard duration in reference memory which is presented within more than one modality. For example, Penney, Gibbon, and Meck (2000, Experiment 1) conducted a bisection experiment in which the participants were presented with a short and a long standard duration a couple of times. These standard durations were presented auditorily and visually in the training phase, after which a testing phase took place in which time intervals of different duration were presented in either modality. The task of the participants was to make judgments about the similarity of the durations of the testing phase with respect to the short or the long standard duration. One of the main results of this experiment was that visually displayed stimuli were judged to be shorter in duration than auditorily displayed stimuli of physically equal duration. In terms of SET, this modality effect of time estimation was due to differences in the speed of the pacemaker which was supposed to be dependent on the modality of the stimuli to be timed. The duration of auditory stimuli should be encoded with a higher pacemaker speed than the duration of visual stimuli. Therefore, more pulses should be accumulated per time unit when an auditory stimulus is presented than when a visual stimulus is presented (Penney et al., 2000; see also Penney, Allan, Meck, & Gibbon, 1998; Wearden, Edwards, Fakhri, & Percival, 1998).

The occurrence of a modality effect in spite of a bimodal training phase let Penney and co-workers (Penney et al., 2000) conclude that each standard was represented as a “mixture” of both the auditory and visual standard duration representations. They called this effect “across-modality memory mixing” and inferred that if an individual encodes a standard interval that is presented by both an auditory and a visual stimulus, a single memory distribution will arise that represents both the auditorily and the visually encoded standard. As the “mean value” of the bimodal distribution of a standard was supposed to be larger than the encoded duration of a visual stimulus of physically equal duration, it should be judged as being shorter than the standard; and vice versa, the duration of an auditorily displayed stimulus which nominally equaled the standard should be judged as being longer than the bimodal standard.

However, the occurrence of across-modality memory mixing was not dependent on the bisection method. Klapproth (2004, Experiment 1) examined whether memory mixing could be replicated when a temporal generalization task, combined with auditory and visual stimuli, was applied. The generalization task was composed of a training phase and a subsequent testing phase. In the training phase the participants received a 400-ms standard interval which was repeatedly presented within either the visual or the auditory modality, allowing them to build up a “mixed” representation of the standard. In the testing phase the participants were presented with stimuli of different duration. After each stimulus presentation the participants had to decide whether or not the duration of the stimulus was the standard duration. Two between-subjects conditions were realized in which the modality of the test stimuli was either auditory or visual. The main result of this experiment was the occurrence of a clear mixing effect, that is, in the visual condition the participants responded more frequently with “yes” (“yes, this duration is identical with the standard duration”) at intervals larger than the standard than in the auditory condition. In Experiment 2 of the Klapproth study the design of the experiment was equivalent to that of the previous one, except for the instruction. Whereas in the first experiment the participants were told that in the training phase the duration of the standard was always the same, regardless of stimulus modality, the participants of the second
experiment were made to believe that the auditory standard differed from the visual standard, though both were actually the same. The results of this experiment showed no mixing effect at all. The proportions of “yes” responses of both conditions differed just marginally without any statistical significance. Klapproth concluded that “the instruction regarding the putative difference of the standards prevented a mutual shift of the gradients and therefore memory mixing” (Klapproth, 2004, p. 429).

The latter result resembled that one recently obtained from Wearden, Todd, and Jones (2006). In their first experiment, a mixed-modality bisection task was used in which the modality of the stimuli was segregated into four distinct blocks. As in this experiment no memory-mixing effect occurred, Wearden and co-workers suggested that memory mixing was avoided “if the experimental design allows a clear distinction between the standards for different conditions” (p. 1714).

Performance decrements in duration discrimination that appear to originate from an underlying memory mechanism can also arise from insufficient cues provided at the time of testing. As Zentall (1997, 2005) suggested, decrements in tasks that require participants to make use of some kind of memory are often a result of instructional failure, meaning that memory is available, but there is confusion as to which response to make.

Results reported by Grondin (2005) might also be interpreted as a consequence of instructional failure. In his experiment, there were two sets of durations, one comprising six durations surrounding a mean of 250 ms, the other comprising six durations surrounding a mean of 750 ms. On each trial, the participants were presented with one duration and had to indicate whether the duration presented was either “short” or “long”. In some conditions, durations obtained from only one set were administered. However, in other conditions, durations from both sets were presented alternately. These conditions were supposed to yield an increased cognitive load, as the participants were not told which duration belonged to which set and thus additionally had to judge whether the presented duration corresponded to either the short or the long set. Grondin found that using two sets of durations increased the number of discrimination errors, compared with results obtained in conditions with only one set of durations.

A recent example of instructional ambiguity realized in temporal generalization stems from De Lurdes Delgado and Droit-Volet (2007). Participants of their experiment received five presentations of the standard before the testing phase began. In one condition (the “fixed referent” condition), the standard duration was always 4 s, whereas in the other condition (the “variable referent” condition) the standard was randomly chosen on each trial from the following durations: 3 s, 3.5 s, 4 s, 4.5 s, and 5 s. The mean of the durations of the variable condition corresponded to the standard duration of the fixed condition. In both conditions, the participants were instructed to decide whether or not comparison durations presented in the testing phase were of the same duration as the standard. That is, the participants of the variable condition were not forced to distinguish between the different durations they encountered during the training phase. Instead, they were encouraged to treat them as one single reference duration although the difference between the shortest and the longest duration of this sample was two seconds. Compared to the fixed condition, the gradients of the variable condition peaked at the same interval (4 s), but their shape was flatter. De Lurdes Delgado and Droit-Volet suggested that the flattening of the gradient was due to both a greater variability of the memory representation of the standard and a less conservative decision threshold. Apparently, a less specified, hence ambiguous instruction let the participants use a mixture of all standards presented previously to them to judge the comparison durations in the testing phase. Whether or not the standards presented in the training phase had really been merged into an average duration (which actually would mean a loss of information regarding the distinct standards), remained unclear.

On the other hand, Wearden and Jones (2007) showed that people can average durations together if instructed to do so. In their second experiment they applied a temporal-generalization task within which participants received three different durations of which they had to form a standard by simply averaging them. This averaged standard then served as the
referent duration against which the following test durations had to be compared. Despite not being presented with a distinct standard duration, the gradients of temporal generalization peaked at the arithmetic mean of the durations of which the average had to be built.

Although people are obviously able to average durations, it is not clear whether this process leads to a loss of the original information (which would be the case if all standard durations would be merged into a single “average duration”), or instead reflects a strategy people use to cope for instructional ambiguity (without loosing access to any standard duration stored in memory). Therefore, one aim of this study was to examine whether instructional ambiguity can be a source of the memory-mixing effect.

Penney et al. (2000) explained the modality effect observed in their bisection experiments, and hence memory mixing, as a result of the modality-dependent speed of the pacemaker. If the visual standard was encoded with a lower speed of the pacemaker than the auditory standard, then, compared to the auditory standard, the visual standard would be represented by less pulses. If this assumption holds true, a similar effect should arise if two slightly different intervals would be encoded as standards within one modality. Thus, the second aim of this study was to investigate whether memory mixing would occur within one modality.

Experiment 1

Experiment 1 was an analogue of the crossmodal experiment conducted by Klapproth (2004, Experiment 1), and it examined whether memory mixing would occur within a single-modality temporal generalization task. This task was subdivided into a training phase and a subsequent testing phase. Three conditions were realized. In condition 1 and 2, participants received presentations of two visual stimuli of slightly different duration within the training phase, of which the short one corresponded to the visual standard and the long one to the auditory standard of the Klapproth (2004) study. In Condition 1, the “same” condition, the participants were told that both intervals were of the same duration and, hence, were labelled “the standard”. However, in Condition 2, the “different” condition, the participants were informed about the difference of both intervals. In this condition, the participants were instructed that both intervals will serve as standards for later comparisons. The participants of Condition 3, the “control” condition, received just the shorter of both intervals as a standard.

In the testing phase, visual stimuli of different duration were presented. The participants of the “same” condition were instructed to decide whether the duration of each stimulus was equal to “the standard” or not. Note that in this instruction there was no explicit differentiation between the de facto different standards of the training phase. In the “different” condition, however, the participants should decide whether or not the presented stimulus durations were equal to “the short standard”. Finally, in the “control” condition, the participants received the same instruction as in the “same” condition, as there was only one standard with which presented stimulus durations could be compared.

Experiment 1 was designed to produce a memory-mixing effect through instructional ambiguity within the visual modality. It was hypothesized that in the “same” condition memory mixing should occur, whereas in the “different” condition and in the “control” condition no mixing effect was expected to occur. That is, compared to the “different” condition and the “control” condition, the gradient of generalization should be shifted to the right in the “same” condition.

Method

Participants

30 students from the University of Hildesheim (13 men and 17 women) were randomly assigned to three equal sized groups. Mean age was 28.6 years (SD = 7.6).

Stimuli and Apparatus

The stimuli were grey rectangles (6 x 12 cm) displayed in the middle of a black computer screen (50 Hz refresh rate). Exposure time of the stimuli was varied between 100 ms and 700 ms. The short standard duration was 400 ms, the long standard duration was 500 ms. Comparison durations were 100, 200, 300, 400, 500, 600, and 700 ms.
A Pentium-II computer controlled all experimental events and recorded the data. Responses were made on the computer keyboard. The experimental program was written in a script-based language (Experimental Run Time Systems [ERTS], version 3.28), from BeriSoft Cooperation, Frankfurt, Germany. ERTS assures millisecond accuracy for timing of stimuli and responses.

Procedure
The procedure of this task corresponded to the kind of temporal generalization task used by Klapproth (2002) for the most part. Each individual participated in the experiment in a moderately illuminated room. All instructions were presented on the computer monitor screen.

Within the training phase participants were instructed to pay attention to a distinct time interval called the standard which was 400 ms. The participants received five presentations of the standard. Then, a temporal generalization task followed. This task began with the presentation of the standard which was succeeded by a comparison stimulus with either equal or different duration. The participants had to decide by pressing the yes or the no key whether or not the duration of the comparison stimulus equalled the duration of the standard. The participants received positive feedback after correct decisions (“Your decision was right.”), and negative feedback after wrong decisions (“Your decision was wrong.”).

After this “short standard” training block a “long standard” training block followed which was again composed of the presentation of a standard interval (500 ms) occurring five times and a temporal generalization task. The presentation order of the “short standard” training block and the “long standard” training block was balanced between subjects.

In the “control” condition, only one training block was applied in which the short standard was presented five times and then the temporal generalization task followed.

Each temporal generalization task of the training phase consisted of 20 trials, separated into two blocks. For each trial there was a nominal probability of $p = .40$ that the presented comparison duration would be the same as the standard. As there were six non-standard durations, the nominal probability for presenting each non-standard duration was $p = .10$. Duration values were chosen randomly within one block.

Within the training phase the participants of the “same” condition were told that the exposure time of both standard stimuli had been the same, although they were in fact different. The instruction text was as follows: “After having been presented with the standard duration, you will receive the same standard duration in a second training block in order to improve your mental representation of this standard.” A later inquiry indicated that the participants did not notice the difference of both standard intervals.

The participants of the “different” condition were informed about the difference of the standard intervals. The corresponding instruction text was: “After having been presented with the standard duration, you will receive a second standard interval which is different from the first one.” In the original experiment all instructions were given in German.

After the training phase the testing phase began which again was a temporal-generalization task where the participants were repeatedly presented with stimuli of different duration. As opposed to the temporal-generalization task of the training phase, only one duration was presented within each trial, and the participants had to decide whether the presented duration was the same as the standard duration or different from it. Moreover, feedback about the correctness of the participants’ decisions was omitted.

The participants of both the “same” condition and the “control” condition were asked to compare the duration of the presented stimuli with the standard interval of the training phase. Note that for the “same” condition the standard was in fact a composition of the short and the long standard duration. The participants of the “different” condition had to relate the presented stimulus durations to the short standard duration.

For the participants of the “control” condition and the “different” condition, the instruction should have been clear, since the assignment of presented intervals in the testing phase to the standard interval of the training
phase was non-ambiguous. However, for the participants in the “same” condition the instruction was ambiguous as there were actually two standard intervals presented in the training phase.

The testing phase consisted of 100 trials, subdivided into ten blocks. The stimulus durations were chosen randomly within one block. The nominal probabilities for the presentation of the standard and the non-standard durations were the same as in the training phase.

**Results and Discussion**

Figure 1 shows the generalization gradients (i.e. the mean proportions of yes responses, plotted against stimulus duration) of the testing phase of both the experimental conditions and the control condition.

![Figure 1. Temporal generalization gradients (mean proportions of yes responses plotted against stimulus duration) obtained in the testing phase of Experiment 1. Circles represent data from the “same” condition, squares represent data from the “different” condition, and triangles represent data from the “control” condition.](image)

An overall analysis of variance with condition as between-subjects factor and stimulus duration as within-subjects factor produced a significant main effect of duration, $F(6, 162) = 50.91$, $p < .001$, and a significant interaction between duration and condition, $F(12, 162) = 1.90$, $p < .05$, indicating that there were differences between the gradients. The main effect of condition, however, was not significant, $F(2, 27) = 0.04$, $p = .96$.

Both the gradient of the “different” condition and the gradient of the “control” condition were approximately symmetrical around their peak and resembled the gradient’s shape of the visual condition of Experiment 1 of the Klapproth (2002) study. Compared to the gradients of the “different” condition and the control condition, the gradient of the “same” condition was shifted to the right. The size of the shift was measured by calculating an asymmetry index defined by the difference between the sum of proportions of yes responses which occurred after the presentation of intervals larger than the standard and the sum of proportions of yes responses, occurring after the presentation of intervals smaller than the standard (see also Wearden et al., 1998, p. 101). If there was any asymmetry within the gradient, this index would provide a positive or a negative value. A positive value indicated that the participants responded more frequently with yes at intervals larger than the standard than at intervals smaller than the standard. A negative value meant the reverse: More yes responses were given at intervals smaller than the standard than at intervals larger than the standard. The mean value of the asymmetry index for the “same” condition was $ASYM = 1.03$ ($SD = 0.76$), for the “different” condition $ASYM = 0.30$ ($SD = 1.04$), and for the control condition $ASYM = 0.22$ ($SD = 0.95$). A planned contrast was calculated to determine whether the difference between the asymmetry index of the “same” condition and the average asymmetry index of both the “different” condition and the control condition was significant. Indeed, a t-value of $t(28) = -2.15$, $p = .021$ (one-tailed) indicated support for the memory mixing hypothesis.

To preliminarily consider the results of this experiment, it could be stated (1) that the occurrence of memory mixing depended on the presence of an explicit specification of the standard pertinent to the task, and (2) that memory mixing was modality-independent. Whereas in recent studies cross-modal comparisons between presented time intervals and some stored standard intervals revealed the mixing effect (cf. Penney, et al., 2000; Klapproth, 2004; Wearden, et al., 2006), a similar effect could be shown in this experiment, when two standards were slightly different in duration and were presented within the visual modality.

However, it still remained unclear whether or not instructional ambiguity led to a mixture of both standard durations (of which a
simple form would be producing an average standard). Alternatively, both standards could have been stored separately in reference memory, rather than being averaged. If the standards would be averaged in the training phase, the participants would hardly be able to distinguish both standard durations in the subsequent testing phase. However, if the standards would be stored separately, distinguishing between both standards might still be possible. Experiment 2 was designed to explore this question.

Experiment 2
With Experiment 2 it was examined whether telling the participants in the training phase that both intervals were the same (i.e., instructional ambiguity) might lead to an averaging of both durations in reference memory. For this purpose, the training phase was composed of two blocks in which the participants were presented with two different standard durations (400 ms and 500 ms), accompanied with the false instruction that both standards were of the same duration. In the subsequent testing phase this instruction was corrected. Thereafter, the participants were asked to compare presented time intervals with the standard duration from either the training block with the short standard (Condition 1) or the training block with the long standard (Condition 2).

On the supposition that the averaging hypothesis is valid, the selection of either standard duration from reference memory should not be possible, due to the preceding false description of the standards as being of the same duration. Hence, memory mixing, that is, an overlapping of both gradients, should occur.

Method
Participants
38 students from the University of Technology in Berlin were randomly assigned to two equal-sized groups. 17 were men, 20 were women, and the sex of one participant was not recorded. Mean age was 25.9 years (SD = 4.6).

Stimuli and Apparatus
As in Experiment 1, the stimuli were grey rectangles (6 x 12 cm), presented on the black screen of a computer monitor (50 Hz refresh rate). The short standard duration was 400 ms, the long standard duration 500 ms. The comparison durations were 100, 200, 300, 400, 500, 600, 700, and 800 ms. The computer equipment was the same as in Experiment 1.

Procedure
The training phase of Experiment 2 was comparable to the training phase of the “same” condition of Experiment 1. In the first training block, the participants were presented with the short standard (400 ms) five times, and then a temporal generalization task followed, in which they received 20 trials, separated into two blocks of 10 trials. The range of presented durations was from 100 ms to 700 ms, the nominal probability for each trial was $p = .40$ for the presentation of the 400-ms standard, and $p = .10$ for the presentation of each non-standard comparison. The second training block followed in which the long standard (500 ms) was presented five times, and then again a temporal generalization task was executed. Here, the range of presented durations was from 200 ms to 800 ms, and the nominal probability for the occurrence of the 500-ms standard was $p = .40$, and for each non-standard duration $p = .10$. The order of the training blocks was changed after approximately half of the participants of each condition (exactly after the 10th participant in each condition). In both conditions, the participants were told in the training phase that both standards were of the same duration.

At the beginning of the testing phase, the participants received a correcting clue regarding the duration of the standards. The instruction text was as follows: “Now we would like to correct a piece of information given to you at the beginning of the experiment. For experimental purposes, you were told that both the standard duration of the first training block and the standard duration of the second training block were the same. This was not the case. The standard of the first training block and the standard of the second training block were in fact different in duration. Please consider this information when reading the following instructions.” After the participants had read this text, the temporal generalization task began. The participants of Condition 1 were asked to...
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compare subsequently presented intervals with either the standard of the first training block, if the short standard was presented within the first training block, or with the standard of the second training block, if the short standard was presented within the second training block. Accordingly, the participants of Condition 2 had to compare presented intervals with either the standard of the first training block, if the long standard was presented within the first block, or with the standard of the second training block, if the long standard was presented within the second training block.

The participants had to judge after each stimulus presentation whether or not the presented stimulus duration was the standard. Feedback regarding the correctness of their judgments was not reported.

Each participant received 96 trials in the testing phase, separated into 12 blocks. All stimulus durations were presented in the testing phase and were chosen randomly within one block. The nominal probabilities for the presentation of each standard was $p = 0.25$, and for each non-standard comparison $p = 0.08$.

Results and Discussion

The gradient of Condition 1 had its peak at the 400-ms stimulus and was slightly asymmetrical, indicating that more yes responses were given at intervals larger than the 400-ms standard than given at intervals smaller than the 400-ms standard. However, the gradient of Condition 2 had its peak at the 500-ms stimulus. Except for the 400-ms stimulus, more yes responses occurred at intervals larger than the 500-ms standard than at intervals smaller than the 500-ms standard.

An overall analysis of variance with condition as between-subjects factor and stimulus duration as within-subjects factor yielded no significant main effect of condition, $F(1, 36) = 0.31, p = 0.58$, but a significant main effect of duration, $F(7, 252) = 31.35, p < 0.001$, and a significant interaction between duration and condition, $F(7, 252) = 2.96, p < 0.01$. The latter result points to the difference of both gradients.

As in Experiment 1, I measured the amount of the mutual shift of the gradients by applying the asymmetry index. The mean value of the asymmetry index for Condition 1 was $ASYM = -0.09$ ($SD = 1.01$) and for Condition 2 $ASYM = 0.84$ ($SD = 1.26$). The difference between both index values was significant, $t(36) = -2.51, p < 0.01$ (one-tailed).

With the results of Experiment 2 the averaging hypothesis must be rejected. Obviously, both standard intervals were mentally represented as two distinct time intervals. The additional rectification of the instruction enabled the participants to selectively choose one of both encoded standard intervals for comparison with presented stimulus durations. Therefore, memory mixing appears to be the result of vague retrieval instructions rather than a consequence of a “mixture” of time values representing the short and the long standard duration.

General Discussion

Two aims were pursued by this study. First, it was examined whether instructional ambiguity with regard to two standard durations presented in the training phase would affect the discrimination of time intervals in the testing phase within the visual modality. It was further explored whether instructional ambiguity would encourage representing two standard durations as an average of both in reference memory.

Previous investigations (Penney et al., 2000; Klapproth, 2004) reported memory mixing only within cross-modal comparisons between current time intervals and stored standard
intervals. The occurrence of cross-modal memory mixing was traced back to modality-dependent differences in the speed of the internal clock. Within the framework of SET, it was assumed that the duration of an auditory event would be paced by a faster clock than the duration of a visual event. Thus, the same duration was associated with a larger time value stored in reference memory when derived from an auditory event than when derived from a visual event. When individuals compare current time intervals with a standard encoded within both the auditory and the visual modality, they apparently use both the auditorily and the visually encoded standard for comparison so that each interval was compared with a “mixture” of both standard representations.

However, the results of Experiment 1 of this study showed that memory mixing also happened within a pure visual modality. Obviously, the “mixture” of time values represented in memory could be realized by using two different standard durations within one modality.

Moreover, it could be shown that the occurrence of memory mixing depended on ambiguity of the instructions. If in the training phase both standard durations were erroneously declared to be the same, memory mixing did occur in the testing phase. If, however, both standard durations were described as being different from one another, memory mixing was not observed.

Furthermore, instructional ambiguity did not result in averaging both standard durations presented within the training phase, as it was shown with Experiment 2. Although the participants were made to believe that they had received just one single standard duration in the training phase (whereas in fact it were two standards), they were able to differentiate both standard durations in the testing phase. They apparently were able to retrospectively assign comparison durations to one of both standard durations without any major difficulty. It might have been possible that the participants of Experiment 2 were aware of the difference between both standards in spite of the delusive instruction in the training phase. However, when the participants were told that both standards were equal in duration, and they were subsequently asked to compare presented intervals with “the standard” (as it happened in the “same” condition of Experiment 1), then the participants were not able to make a clear assignment between that time interval and one of the standards. As a consequence, memory mixing occurred.

On a behavioural level, memory mixing appears to be a decrease of discrimination in a time-estimation task. For example, in the “same” condition of Experiment 1, the participants could not differentiate between the 400-ms stimulus and the 500-ms stimulus on average. Penney and co-workers (Penney et al., 1998, 2000) reasoned that this performance deficit was caused by a merger of encoded time values into one single memory distribution. They proposed that in the cross-modality case the participants used as the standard a single memory distribution for both modalities rather than separate memory distributions for each modality (Penney et al., 2000, p. 1774). Moreover, the authors quantified the mixture of time values that represented the standard: “The memory representation may be thought of as an average to which the accumulations (...) for each modality contribute.” (Penney et al., 2000, p. 1774).

The averaging hypothesis was recently tested by Jones and Wearden (2003) within a different context. They manipulated the number of standard presentations in a temporal-generalization task, so that the participants received one, three, or five identical presentations of the standard, and then responded to a series of comparison stimuli. If the successive individual examples of the standard would be aggregated together, increasing the numbers of successive presentations of a standard should make the aggregated value more accurate, hence leading to better performance in the testing phase. However, if the different examples of the standard would be stored completely separately and then sampled, number of presentations should have no effect on performance. Jones and Wearden found that number of presentations did not affect the shape of the generalization gradients. Their conclusion on this finding was that instants of a reference duration that are presented a number of times prior to the testing phase are not averaged, or mixed, together but instead kept separate in an array,
and on each trial of the testing phase a value from this array is randomly sampled and compared with the test duration at hand.

Accordingly, if there are two different standards presented prior to the testing phase (as it was the case in this study), each of these standards should be represented separately. To compare a time interval with one of the standards, a sample from reference memory will be drawn which will be related to the current interval. It can be assumed that with instructional ambiguity time values representing the short standard would be sampled with the same probability than time values representing the long standard. This means that over a successive series of trials both standards would enter the comparison process with approximately equal frequency, so that the time estimations an individual carries out would look as if he or she compares current intervals with the mean of both standard intervals.

The results of the present study indicate that memory mixing appears to depend solely on the lack of a precise relation between the current time interval and the appropriate standard rather than on a mixture of time values represented in reference memory. If the participants were able to make a clear assignment between a current interval and the standard, memory mixing failed to occur. It is reasonable to assume that the participants stored both standard durations separately, presumably as two distinct, although surely overlapping distributions of subjective standard times. What should be examined in future investigations is the question regarding the psychological mechanisms that allow for the selection of each standard represented in memory. How are people able to selectively draw a sample from different standard durations stored in reference memory even if the standards are similar in duration? For example, experiments will be needed that explore whether time of encoding aids the selection of either standard duration.

References


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