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Mixing costs and mixing benefits in naming words, pictures, and sums☆

Stephen J. Lupker,[a,*] Sachiko Kinoshita,[b] Max Coltheart,[b] and Tamsen E. Taylor[a]

[a] *Department of Psychology, University of Western Ontario, London, Ont., Canada N6A 5B7*
[b] *MACCS, Macquarie University, Sydney, NSW, Australia*

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Abstract

When two types of stimuli are mixed in a trial block, each stimulus type is typically responded to more slowly than when those stimuli are presented by themselves in pure blocks (a "mixing cost," Los, 1996). In word/non-word naming tasks, however, mixing two types of stimuli leads to a different, "homogenization," pattern. There is a mixing cost for the easier stimuli and a mixing benefit for the more difficult stimuli (Lupker, Brown, & Colombo, 1997). In the present research we investigated the generality of this homogenization pattern by examining picture naming and a sum-naming task involving addition problems (e.g., 10+7 = ?). In Experiments 1 and 2, the homogenization pattern was observed for both pictures and sums. In Experiments 3 and 4, qualitatively different stimulus types (words and pictures, words and sums) were mixed. The mixing cost pattern was observed. Experiments 5 (words and pictures) and 6 (words and sums), however, demonstrated that a homogenization-type pattern can be obtained even when qualitatively different stimulus types are mixed. These results indicate that theoretical mechanisms like those proposed by Los (1996) and theoretical mechanisms like those proposed by Lupker et al. (1997) are both active in reaction time experiments.

Keywords: Time criterion; Naming task; Homogenization pattern; Mixing cost pattern; Pure vs. mixed blocks

When designing an experiment, one issue that every researcher must deal with is whether to present each condition of the experiment in a separate block of trials (a "pure block" design) or whether to combine all the conditions in a single block of trials (a "mixed block" design). The choice can have considerable consequences for the ultimate interpretation of the results. That is, pure blocks provide the optimal opportunity for the use of condition-specific strategies, which can lead, at the very least, to quite different levels of performance in the pure vs. mixed block situations. Pure blocks also, of course, allow for an examination of these proposed strategies, an issue that has recently attracted considerable attention in the word recognition and speech production literature (Baluch & Besner, 1991; Kang & Simpson, 2001; Kawamoto, Kello, Jones, & Bame, 1998; Kello, Plaut, & MacWhinney, 2000; Lupker et al., 1997; Meyer, Roelofs, & Levelt, 2003; Monsell, Patterson, Graham, Hughes, & Milroy, 1992; Schriefers & Teruel, 1999; Simpson & Kang, 1994; Tabossi & Laghi, 1992; Zevin & Balota, 2000).

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* Corresponding author. Fax: +519-661-3961.
E-mail addresses: lupker@uwo.ca (S.J. Lupker), sachiko@maccs.mq.edu.au (S. Kinoshita).

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Over the past 40 years, considerable research effort has been expended trying to answer the general questions of how and why pure vs. mixed block performance differs and what these differences imply about our ability to enact processing strategies (e.g., Forrin, 1975; Gordon, 1983; Grice, 1968; Kiger & Glass, 1981; Los, 1999a, 1999b; Meuter & Allport, 1999; Niemi, 1991; Rogers & Monsell, 1995; Sanders, 1977, 1990; Strayer & Kramer, 1994a, 1994b; Thomas & Allport, 2000; see Los, 1996 for a review). The data pattern most often found in these studies has been that the latencies in both conditions are longer in mixed blocks than in pure blocks (a "mixing cost" pattern). Further, as Los (1996, 1999a) points out, this cost is often asymmetric. There is a greater cost for the condition that has the shorter latency in pure blocks than for the condition that has the longer latency in pure blocks.

As Los (1996) notes in his review, the mechanisms that have been proposed to explain these mixing costs tend to be of two types. One is based on the idea that mixed blocks require participants to keep in mind strategies for dealing with both conditions. That is, the conditions typically involve either different stimulus types or different tasks and because participants are uncertain which stimulus type (or task) will be presented on the next trial, they cannot effectively prepare for it like they can in pure blocks. The second type of mechanism is based on the fact that, because there are different types of stimuli and/or tasks in mixed blocks, different mental activities need to be invoked for the two different conditions. Because it is effortful to switch from one mental activity to the other, mixed block latencies will be longer than latencies in pure blocks, blocks in which no switching is required. These two accounts are, of course, not mutually exclusive and, indeed, it seems likely that mixing costs are due both to preparation difficulties and to problems switching from one mental activity to the other (e.g., Meiran, 2000).[1]

In more recent years, however, a slightly different mixed-pure block pattern has appeared. Using a word- (or non-word) naming task, Lupker and colleagues (Desrochers, Gonthier, & Lupker, 2003; Lupker et al., 1997; Taylor & Lupker, 2001) have demonstrated a latency homogenization effect in mixed blocks (hereafter referred to as the "homogenization pattern"). That is, although latencies in the easier ("fast") condition are longer in mixed than pure blocks (a mixing cost), latencies in the more difficult ("slow") condition are shorter in mixed than pure blocks (a mixing benefit). While it is certainly possible to explain the mixing cost for the fast condition in terms of either of the mechanisms described by Los (1996), neither mechanism can provide an explanation for the mixing benefit for the slow condition. According to either notion, pure blocks should allow participants to adopt the optimal processing strategy. The only effect that mixing stimuli and/or tasks can have would be detrimental.

Explanations for the homogenization pattern have, therefore, been framed somewhat differently. Some researchers (e.g., Monsell et al., 1992) have suggested that there is a shift in the nature of processing between blocks, a shift that involves putting more or less emphasis on one of the two routes (i.e., the lexical route or the non-lexical route) in Coltheart and colleagues' (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) dual-route model. While a shifting-of-route-emphasis account cannot be conclusively ruled out as an explanation for some homogenization effects (see Kinoshita & Lupker, 2003; Zevin & Balota, 2000), these effects have been obtained across a wide range of situations (Chateau & Lupker, 2003; Lupker et al., 1997; Taylor & Lupker, 2001), including many in which a shifting-of-route-emphasis account simply would not apply. For example, Lupker et al. (1997) reported a homogenization effect when low and high frequency exception words were mixed. Because both word types require the use of the lexical route in order to be named accurately, that route should have been maximally emphasized in all blocks. Thus, there should have been no pure block-mixed block differences. As a result, Lupker and colleagues (Chateau & Lupker, 2003; Kinoshita & Lupker, 2002, 2003; Lupker et al., 1997; Taylor & Lupker, 2001) have proposed that homogenization effects are due, not to a shift in the nature of processing between the pure and mixed blocks, but to a re-positioning of a criterion in the different blocks.

Most models of word naming (e.g., Coltheart et al., 2001) are based on the idea that there is what Taylor and Lupker (2001) referred to as a "quality criterion." That is, processing continues until the phonological code and/or articulatory code reach a particular level of quality. At that point, sufficient information has become available to allow successful processing downstream. Strategic changes in the placement of this criterion would, of course, produce changes in response latency. As Taylor and Lupker note, however, although a quality criterion clearly must play some role in the word naming process, the homogenization pattern, itself, is not easily explained in terms of changes in its placement.

Instead, what Lupker and colleagues (Chateau & Lupker, 2003; Kinoshita & Lupker, 2002, 2003; Lupker et al., 1997; Taylor & Lupker, 2001) have proposed is that on each trial, participants set a time criterion representing the time at which they expect to begin articulation. The position of the time criterion is determined both by the global context (e.g., the degree to which the

[1] The nature of the mechanism responsible for the second type of mixing cost—the switch cost—is currently hotly debated (e.g., Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995). Because this is not an issue directly relevant to our concerns, we will not discuss it here.

instructions emphasize speed or accuracy) and the local context (e.g., how fast the response was on the previous trial(s), see Taylor & Lupker, 2001). Participants then attempt to respond at that point in time on that trial. In a pure fast block, the criterion is set early. In a pure slow block, it is set late. In a mixed block, it is set at an intermediate position. Participants typically do not succeed in responding precisely at the point that the time criterion is reached, of course. However, the impact of their attempts to do so is: (a) to increase latencies in the fast condition in mixed blocks compared to pure blocks and (b) to decrease latencies in the slow condition in mixed blocks compared to pure blocks. Although there are aspects of the time-criterion account that still need to be developed (see General discussion), this account provides a ready explanation of the homogenization pattern.

An alternative account of the homogenization pattern, which is also not an account based on a shift in the nature of processing, has been proposed by Kello and Plaut (2000, 2003). Kello and Plaut have suggested that what participants do is to adjust the level of a processing speed parameter (the "input gain") as a function of the processing difficulty of the stimuli in the trial block. Input gain can be turned up when all the stimuli are easy because the chances of an error are minimal. Hence, latencies are quite fast in pure easy blocks. The input gain must remain low when all the stimuli are hard because increasing input gain would tend to make the system too error-prone. Hence, latencies are quite slow in pure hard blocks. In mixed blocks, an intermediate level of input gain is selected, leading to homogenized latencies. Thus, both theories provide reasonable accounts of Lupker and colleagues' homogenization pattern. (The subsequent discussion of the homogenization pattern will be couched in terms of the time-criterion account. We will postpone a discussion of the implication of our effects for the input gain account until the General discussion.)

The focus of the present research is this homogenization pattern and the conditions under which it, rather than the mixing cost pattern, arises. To this point, mixing costs have been demonstrated across a number of different domains. For example, they have been demonstrated with various types of stimuli (e.g., letters and digits, Forrin, 1975; tones, Grice & Hunter, 1964; lights, Niemi, 1991; words, Gordon, 1983) and with various types of tasks (e.g., simple RT, Grice & Hunter, 1964; Niemi, 1991; choice RT, Sanders, 1977; lexical decision, Gordon, 1983). In contrast, all the homogenization effects reported by Lupker and colleagues (Lupker et al., 1997; Taylor & Lupker, 2001) have come from word- (or non-word) naming tasks. Thus, in the experiments reported here, we concentrated on naming tasks and set out to examine whether the homogenization pattern is specific to the naming of words/non-words (and, hence, needs to be explained within models of the word-naming process) or whether it is found more generally across naming tasks involving other types of stimuli.

In Experiment 1, the stimuli were pictures. Based mainly on Snodgrass and Yuditsky's (1996) norms, we selected two sets of pictures, one set that should be named rapidly (the "fast pictures") and one set that should be named more slowly (the "slow pictures"). Picture naming and word naming have a number of parallels as well as a number of differences. Where they differ is mainly in the nature of the early processing (e.g., orthographic processing for words vs. semantic processing for pictures). Where one finds parallels is in the later processing, in particular, in the phonologically based processing that leads up to the naming response. For example, both require accessing and retrieving information from a phonological lexicon, constructing a phonological representation based on that information and turning that representation into an articulatory code. Given these parallels, if homogenization effects are due to activity of a time criterion, as proposed in the time-criterion account, one would expect that those effects would be found with picture naming just as with word naming.

In fact, Meyer et al. (2003) have recently reported data suggestive of a homogenization pattern in picture naming. In their experiments, Meyer et al. manipulated the number of syllables in the picture's name (one or two). Two of Meyer et al.'s experiments are relevant to the present research. In their Experiment 1, in which the mixed vs. pure block manipulation was a between-subject manipulation, Meyer et al. observed a 24-ms mixing cost for the one-syllable pictures and a 8-ms mixing benefit for the two-syllable pictures. In their Experiment 3, in which the pure blocks always preceded the mixed blocks and the picture stimuli were not counterbalanced across blocks, Meyer et al. observed a 4-ms mixing cost for their one-syllable pictures and a 11-ms mixing benefit for their two-syllable pictures.

Because the issue under investigation was syllable-length effects and not the effects of mixing per se, Meyer et al. (2003) did not analyse these, rather small, mixing effects. Nor did they interpret their data in terms of the operations of a time criterion. Rather, as will be discussed below, their interpretation was based on the notion of a shift in the nature of processing, based specifically on whether the names of the pictures in the trial block had one or two syllables (or whether there was a mixture of the two). What is most important to note at present, however, is that, although Meyer et al.'s data suggest a homogenization pattern, the strength of their manipulation in the pure blocks was not large (i.e., 36 ms in Experiment 1 and 24 ms in Experiment 3). Thus, it would have been hard for them to have found a significant homogenization pattern in any case. The strength of our manipulation in the pure blocks was, purposely, much larger, providing ample opportunity for the homogenization pattern to emerge.

In Experiment 2, the stimuli were sums. Participants were presented with equations of the form "10+7 = ?" and had to provide the correct answer. Again two sets of sums were used. "Fast sums" involved either 0 or 10 as one of their components while "slow sums" did not involve either 0 or 10 but did involve carrying (e.g., Krueger & Hallford, 1984). Sum naming also involves a number of phonologically based processing stages that parallel the later processes involved in naming words. One of the main differences between the two tasks is that the processes involved in accessing the phonological lexicon with sums are more varied (e.g., Campbell & Fugelsang, 2001) than those involved in accessing the phonological lexicon with words. For example, sums can be named by simply retrieving language-dependent number facts (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999). Sums can also be named by calculating a language-independent representation of number magnitude (Dehaene et al., 1999; McCloskey, 1992) and then using it to access the phonological lexicon. There are also a number of other strategies that are available for certain types of sums. For example, if the sum involves a 0 as one operand, participants can simply name the other operand. Nonetheless, given the basic parallels between sum and word naming at the later stages, if homogenization effects are due to activity of a time criterion, as described in the time-criterion account, the expectation is that homogenization effects will be found with sum naming just as with word naming (and with picture naming).

In both experiments, the fast and slow stimuli were presented either in pure blocks or in a mixed block. A completely within-subject design was used. The order of the blocks and the assignment of stimuli to blocks were completely counterbalanced over participants. The empirical question was whether the naming latencies for the fast stimuli would be shorter in pure blocks than in mixed blocks and, more importantly, whether the latencies for the slow stimuli would be longer in pure blocks than in mixed blocks (i.e., whether the homogenization pattern will obtain) using these stimuli.

Experiment 1 (pictures)

Method

Design

The present experiment involved a 2 (block type: pure vs. mixed) $\times$ 2 (picture speed: fast vs. slow) factorial design, with both factors being within-subject factors. The dependent variables were naming latency and error rate.

Participants

Sixty-four University of Western Ontario undergraduates participated in the experiment for course credit. All participants were native Canadian-English speakers.

Materials

The critical stimulus materials were 76 easy-to-name (i.e., fast) pictures and 76 hard-to-name (i.e., slow) pictures. The pictures were chosen from Snodgrass and Vanderwart's (1980) norms based mainly on the latencies reported for those pictures in Snodgrass and Yuditsky's (1996) norms. In addition to having substantially different latencies according to the norms, the pictures differed on a number of descriptive dimensions, with those differences consistently favoring the fast pictures. The dimensions were age-of-acquisition (3.24 vs. 4.09), Kucera and Francis (1967) frequency (65.0 vs. 28.2), familiarity (3.76 vs. 3.03), image complexity (2.65 vs. 3.04), Snodgrass and Vanderwart's (1980) H (0.21 vs. 0.29), length in letters (5.07 vs. 5.64) and length in syllables (1.51 vs. 1.68), with the values representing the fast and slow pictures, respectively. An effort was made to select sets of pictures that had virtually the same (high) level of name agreement (96% vs. 94% for the fast and slow pictures, respectively) in order to try to keep the error rates low and as similar as possible for the two stimulus sets. The pictures used in all the picture-naming experiments are listed in the Appendix.

Both the fast pictures and the slow pictures were divided into two sets, Sets A and B. These sets were used to create two list versions for the purpose of counterbalancing assignment of pictures to block type. The first version contained a pure block of Set A fast pictures, a pure block of Set A slow pictures, and a mixed block containing Set B fast pictures and Set B slow pictures. The second version contained a pure block of Set B fast pictures, a pure block of Set B slow pictures, and a mixed block containing Set A fast pictures and Set A slow pictures. Each participant got a different random ordering of the stimuli within each block.

For each block of trials, six practice pictures representative of the block preceded the experimental pictures.

Apparatus and procedure

Participants were tested individually. Each participant completed three blocks of trials, namely, two pure blocks and one mixed block that contained twice as many stimuli as either pure block. Half of the participants received the mixed block first, and the other half received the pure blocks first. Within the pure blocks, half of the participants received the fast block first, and the other half received the slow block first. The assignment of Sets A and B to the pure/mixed blocks was counterbalanced so that for half of the participants, Set A items appeared in the pure blocks and Set B items appeared in the mixed block; for the other half, Set B items appeared in the pure blocks and Set A items appeared in the mixed block. Thus, a full counterbalancing was realized with every eight participants.

At the outset of the experiment, participants were told that a set of pictures would be shown on the computer screen, one at a time. Participants were instructed to name the pictures as rapidly as possible without making too many mistakes.

The presentation of stimuli was controlled by Macintosh LCIII computer (model number M1254) with OS 7.6.1 system software. Stimuli were displayed by an Apple Multiple Scan 17 Display monitor (family number M2494). Stimuli were presented in the middle of the screen both horizontally and vertically. Naming latencies were recorded using a handheld microphone (Model No. WM2264P; Panasonic) connected to a PsyScope button box. (Participants were instructed to hold the microphone approximately 3–5 cm from their mouth.) Naming errors and measurement errors due to inappropriate vocalizations (e.g., coughing) were recorded manually by the experimenter. Participants were seated approximately 60 cm from the computer screen.

Each trial started with the presentation of a blank screen for 1500 ms, followed by a fixation sign "+" for 1000 ms, a blank screen for 500 ms, then a picture presented centrally. The picture remained on the screen until the voice key was triggered by the participant's response. Participants were given no feedback on either naming latencies or error rates during the experiment.

Results

For this and all subsequent analyses, the preliminary treatment of trials was as follows. Any trial on which a participant or voice key error occurred was excluded from the latency analysis. In order to reduce effects of outliers, latencies shorter than 250 ms or greater than 2500 ms were excluded from all picture-naming analyses. In this experiment, the error rates for errors that the participant was responsible for (i.e., those excluding both mechanical errors (approximately 3.4% of the trials in all conditions) and errors where either an alternative name was given or the identity of the object was unknown (3.5% for the fast pictures and 9.3% for the slow pictures)) were uniformly low, and were therefore not analyzed. In addition, in all experiments involving pictures (i.e., Experiments 1, 3, and 5) latencies from trials following errors were also not analyzed. Subsequent analyses including those trials produced essentially identical results to those reported here. Both analyses treating subjects as a random factor (F_1), and treating items as a random factor (F_2) are reported. Unless otherwise stated, an α level of .05 was used to determine statistical significance in all cases.

For naming latency, we report a two-way analysis of variance (ANOVA) with block type (blocked vs. mixed) and picture speed (fast vs. slow) as factors. In the subject analysis (F_1), both factors were within-subject factors; in the item analysis (F_2), picture speed was a between-item factor. The mean naming latencies and percent error rates from the subject analysis are presented in Table 1.

The main effect of block type was non-significant, $F_1(1,63) < 1.0$; $F_2(1,150) = 1.74$, $MSe = 2340.52$. The main effect of picture speed was significant, $F_1(1,63) = 315.76$, $MSe = 10145.01$; $F_2(1,150) = 184.68$, $MSe = 17531.09$. More importantly, these two factors produced a significant interaction, $F_1(1,63) = 16.00$, $MSe = 4654.82$; $F_2(1,150) = 19.21$, $MSe = 2340.52$. As can be seen from Table 1, the interaction reflected the fact that relative to the pure blocks, the fast pictures were named more slowly (by 41 ms), $t_1(63) = 3.24$, $t_2(75) = 5.29$, and the slow pictures were named more rapidly (by 28 ms), $t_1(63) = 1.69$, $t_2(75) = 1.82$, both $p < .05$, one-tailed, in the mixed block. Thus, picture naming showed the homogenization pattern due to mixing of fast and slow pictures.

Experiment 2 (sums)

Method

Design

Experiment 2 involved a 2 (block type: pure vs. mixed) $\times$ 2 (sum speed: fast vs. slow) factorial design,

Table 1
Mean picture naming latencies (RT, in ms) and percent errors (%E) in Experiment 1

Block type	Picture type					
	Fast		Slow		Difference	
	RT	%E	RT	%E	RT	%E
Pure	862	0.4	1120	0.7	258	0.3
Mixed	903	0.5	1092	1.2	189	0.7
Mixing effect	41	0.1	−28	0.5		

with both factors being within-subject factors. The dependent variables were naming latency and error rate.

Participants

Twenty-four volunteer Macquarie University students participated in this experiment for course credit. All participants were native Australian-English speakers.

Materials

The critical stimulus materials were 28 fast and 28 slow addition problems, solutions to which were the numbers 11–19. All problems were unique, that is, no problem was repeated. The fast problems included either a 10 or a 0 as an addend (e.g., $10 + 7 = ?$). The slow problems included single digits as addends and required carrying (e.g., $8 + 9 = ?$). The fast and slow problems were matched on the solutions so that the vocal output was identical for the two types of problems.

Both the fast and slow problems were divided into two sets, Sets A and B, matched on the solutions (e.g., Set A: $10 + 7 = ?$, Set B: $7 + 10 = ?$). These sets were used to create two list versions for the purpose of counterbalancing assignment of sets to block type. The first version contained a pure block of Set A fast problems, a pure block of Set A slow problems, and a mixed block containing Set B fast problems and Set B slow problems. The second version contained a pure block of Set B fast problems, a pure block of Set B slow problems, and a mixed block containing Set A fast problems and Set A slow problems. For each block, a single random order was generated.

The experimental stimuli were preceded by 10 warm-up problems representative of the block. These problems were similar to the experimental stimuli, but also included subtraction problems (e.g., $19 - 5 = ?$; $11 - 0 = ?$). Finally, for each block, four practice problems representative of the block were used. Neither the warm-up problems nor the practice problems were used as experimental stimuli.

Apparatus and procedure

Participants were tested individually, seated approximately 40 cm in front of an NEC Multisync 4FG monitor upon which the stimuli were presented. Each participant completed three blocks of trials, namely, two pure blocks and one mixed block containing twice as many stimuli as either pure block. Half of the participants received the mixed block first, and the other half received the pure blocks first. Within the pure blocks, half of the participants received the fast sum block first, and the other half received the slow sum block first. The assignment of Sets A and B to the pure/mixed blocks was counterbalanced so that for half of the participants, Set A items appeared in the pure block and Set B items appeared in the mixed block; for the other half, Set B items appeared in the pure block and Set A items appeared in the mixed block. Thus, a full counterbalancing was realized with every eight participants.

At the outset of the experiment, participants were told that a list of arithmetic problems would be shown on the computer screen, one at a time. Participants were instructed to compute the solution, then to say the solution aloud as soon as possible.

Instructions and stimuli were presented and reaction time data recorded to the nearest millisecond using the DMASTR display system developed by K.I. Forster and J.C. Forster at Monash University, Australia, and the University of Arizona (details of this system can be obtained at the internet address: http://www.u.arizona.edu/~kforster/dmastr/dmastr.htm) running on a Deltacom 486 IBM compatible computer. Naming latencies were recorded using an amplitude voice key fitted to each participant and held a constant distance from the mouth throughout the experiment by means of a headset. Naming errors and possible measurement errors due to inappropriate voice key activation were recorded manually by the experimenter.

Each trial started with the presentation of a fixation sign (+) for 500 ms, followed by an arithmetic problem of the form "$10 + 7 = ?$." The problem remained on the screen for a maximum of 2000 ms, or until the voice key was triggered by the participant's response. Following a blank screen for 300 ms, the next trial started. Participants were given no feedback on either naming latencies or error rates during the experiment.

Results

For each of naming latency and percent error rate, we report a two-way ANOVA with block type (blocked vs. mixed) and sum speed (fast vs. slow) as factors. In the subject analysis (F_1), both factors were within-subject factors; in the item analysis (F_2), sum speed was a between-item factor. The mean naming latencies and percent error rates from the subject analysis are presented in Table 2.

For latency, the main effect of block type was nonsignificant, $F_1(1, 23) < 1.0$, $MSe = 2785.11$; $F_2(1, 54) < 1.0$, $MSe = 3593.96$. The main effect of sum speed was significant, $F_1(1, 23) = 90.42$, $MSe = 36733.45$; $F_2(1, 54) = 330.36$, $MSe = 11266.29$. More importantly, these two factors showed a significant interaction, $F_1(1, 23) = 26.47$, $MSe = 2448.13$; $F_2(1, 54) = 17.20$, $MSe = 3593.96$. As can be seen from Table 2, the interaction reflected the fact that relative to the pure blocks, the fast sums were named more slowly (by 48 ms), $t_1(23) = 5.18$; $t_2(27) = 4.70$, and the slow sums were named more rapidly (by 56 ms), $t_1(23) = 3.00$; $t_2(27) = 2.29$, in the mixed block. Thus, sum naming showed the homogenization pattern due to the mixing of fast and slow items.

Table 2
Mean sum naming latencies (RT, in ms) and percent errors (%E) in Experiment 2

Block type	Sum type				Difference	
	Fast		Slow			
	RT	%E	RT	%E	RT	%E
Pure	635	0.3	1059	3.0	424	2.7
Mixed	683	0.0	1003	4.8	320	4.8
Mixing effect	48	−0.3	−56	−1.8		

For error rate, the main effect of block type was nonsignificant, $F_1(1,23) = 1.09$, $MSe = 12.24$; $F_2(1,54) = .67$, $MSe = 22.94$. The main effect of sum speed was significant, $F_1(1,23) = 24.00$, $MSe = 13.77$; $F_2(1,54) = 20.91$, $MSe = 18.53$. These two factors did not interact, $F_1(1,23) = 2.77$, $MSe = 9.18$; $F_2(1,54) = 1.32$, $MSe = 22.94$.

Discussion

The results of Experiments 1 and 2 were clear cut. The same type of homogenization pattern that one finds when naming words was found when participants named both pictures and sums. Fast pictures/sums were named more slowly and slow pictures/sums were named more rapidly when the fast and slow items were mixed, relative to when they were named in pure blocks. Thus, even though the nature of early processing is clearly different for words, pictures, and sums, the naming of all three seems to be affected in the same way by mixing fast and slow stimuli.

It is worth noting that the source of the difficulty manipulation was quite different in Experiments 1 and 2. With the pictures, we were guided by the existing norms in selecting fast and slow pictures. The two sets of pictures differed on a large number of dimensions, for example, age of acquisition, visual complexity, etc. Thus, there were a number of processes (e.g., object recognition, phonological coding) that may have contributed to the difference in response latency. With the sums, the fast sums (e.g., "10 + 5 = ?") involved either 0 or 10 as one of the addends while the slow sums (e.g., "8 + 7 = ?") did not involve either 0 or 10 but did involve carrying. Again, the difference between fast and slow sums may be localized at any number of processes (e.g., the arithmetic computation process, the number fact retrieval process). Also in Lupker et al.'s (1997) and Taylor and Lupker's (2001) word naming experiments, different manipulations of difficulty were used (e.g., high vs. low frequency words, regular words vs. non-words). Nonetheless, in all these experiments, qualitatively similar homogenization patterns were found.

The fact that the homogenization pattern is so ubiquitous does have implications for Meyer et al.'s (2003) explanation of the homogenization patterns in their picture-naming experiments. As noted, Meyer et al. used pictures with one- and two-syllable names as their fast and slow stimuli. They discovered that there was a latency difference between these stimulus types when they were presented in pure blocks, but not in mixed blocks, essentially due to a homogenization of latencies in mixed blocks. They explained this result in terms of differences in the completeness of the articulatory planning in the different blocks. In particular, they proposed that in the mixed blocks, participants initiate articulation "after having recovered the articulatory program for the first syllable of a disyllabic word" (p. 144), whereas "In pure monosyllabic blocks, (participants) also selected one syllable program before beginning to speak, whereas in pure disyllabic blocks they selected two syllables" (p. 145). That is, Meyer et al. proposed an account based on a shift in the nature of processing rather than a time-criterion-based account.

Meyer et al.'s (2003) account would indeed predict that, in mixed blocks, two-syllable words will have reduced latencies and that there will be no syllable length effect. Unfortunately, it does not explain the increased latencies for the one-syllable words in mixed blocks because the first syllable strategy would have been the active strategy in both the pure fast block and the mixed block. Hence, there should have been no mixing effect for one-syllable words. As noted, however, because the authors were not directly looking for mixing effects (but, rather, were concentrating on the syllable-length effect), they did not counterbalance block order and stimuli in a way that would allow the details of the mixing effects to be clear.

Meyer et al.'s (2003) account, therefore, may provide a reasonable explanation for their homogenization pattern. What is clear, however, is that it would not provide an explanation of most, if not all, of the homogenization effects reported in experiments using word stimuli (e.g., Lupker et al., 1997; Taylor & Lupker, 2001). The words and non-words in those experiments were inevitably monosyllabic. A more relevant question, however, is whether their account might provide a reasonable explanation of the homogenization effects in the present experiments.

The answer would appear to be "no." To begin with, our fast and slow pictures in Experiment 1 varied only minimally in terms of number of syllables (1.51 vs. 1.68, respectively) and in terms of the number of one-syllable names (49 vs. 39, respectively, out of 76 pictures). Thus, it would be hard to see why a one-syllable strategy would have been used in the pure fast block and a two-syllable (or, perhaps, complete word) strategy would have used in the pure slow block. Second, both our fast pictures and our slow pictures contributed to the homogenization effect (i.e., the latencies for both were different in the pure vs. mixed blocks). Thus, if one wanted to explain these data in terms of qualitatively different strategies, whatever strategy was being used in the mixed block could not have been the same strategy used in either of the two pure blocks (i.e., either a one-syllable or two-syllable strategy). Instead, it would have had to have been a third, as yet, unspecified, strategy. Finally, the fact that we also observed the homogenization pattern with sum naming suggests that nothing about the articulatory code itself had anything to do with generating the homogenization pattern. As noted, the fast and slow sums had the exact same vocal outputs. Everything considered, it seems very unlikely that the results of the present experiments were driven by strategies based on the syllabic structure of the output. One must, therefore, question whether Meyer et al. (2003) mixing effects could have been due to syllabic-based strategies either.

Experiments 3 and 4

The results of the first two experiments (along with the data reported previously, e.g., Lupker et al., 1997; Taylor & Lupker, 2001) stand in stark contrast to the mixing cost pattern in the experiments discussed by Los (1996). The obvious question is, what is the cause of this discrepancy? Although there are a number of differences between the present paradigm and those showing only mixing costs, a potentially important one is that the experiments showing the homogenization pattern involved the naming task. In contrast, there appears to be only one reported naming experiment which showed the mixing cost pattern (Forrin, 1975, who mixed letters and digits).

Another potentially important difference between paradigms is that the stimuli that were mixed in Experiments 1 and 2 (and elsewhere, e.g., Lupker et al., 1997) very likely did not demand qualitatively different processing routines. Thus, issues of either differential preparation or shifting mental activities (the two proposed reasons for observing mixing costs) may have been irrelevant in these experiments. In contrast, most of the literature surveyed by Los (1996) did involve stimuli and/or tasks that demanded qualitatively different processing routines (although for exceptions, see Gordon, 1983; Grice & Hunter, 1964; Niemi, 1991; Sanders, 1977). Examining these two potential explanations was the goal of Experiments 3 and 4.

The task in Experiments 3 and 4 was, again, a naming task. However, in these experiments, words were mixed with pictures (Experiment 3) and sums (Experiment 4), words being the fast stimuli and pictures/sums being the slow stimuli in the two experiments. The participant's task was to produce a naming response to whatever stimulus was presented. If the homogenization pattern does fall out of any naming task, the expectation is that words will be named slower when mixed with either pictures or sums than when named in a pure block of words whereas pictures or sums will be named more rapidly when mixed with words than when named in a pure block. In contrast, the stimuli that were mixed in the mixed blocks (i.e., words and pictures, words and sums) did indeed require qualitatively different processing routines. Thus, if this factor is the key to obtaining the mixing cost pattern, that pattern should emerge in these experiments even though the tasks involved are all naming tasks and the stimuli used have all shown the homogenization pattern in earlier experiments.

Experiment 3 (pictures and words)

Method

Design

Experiment 3 involved a 2 (block type: pure vs. mixed) $\times$ 2 (stimulus type: words vs. pictures) factorial design, with both factors being within-subject factors. Participants named words and pictures in three blocks: In one block, all the stimuli were pictures, in a second block, all the stimuli were words, and a third block contained both types of stimuli. The dependent variables were the naming latency and error rates for the words and pictures.

Participants

An additional 64 University of Western Ontario undergraduates participated in this experiment for course credit. All participants were native Canadian-English speakers.

Materials

The stimulus materials consisted of 80 words and 80 pictures. The words were all 4–5 letters long and of low frequency (18–23 occurrences per 18 million based on the CELEX corpus, Baayen, Piepenbrock, & van Rijn, 1993, e.g., glade, puck). The pictures had all been used in Experiment 1 and were mainly drawn from the slow picture set. Some of the slower pictures from the fast picture set were added, however, in order to: (a) replace some of the slow pictures that a number of participants had some difficulty recognizing in Experiment 1 and (b) bring the total to 80. (The reason that most of the pictures were from the slow picture set from Experiment 1 was that the Experiment 1 results showed that the latency of those stimuli would decrease when they were mixed with faster stimuli.)

Apparatus and procedure

The apparatus, counterbalancing procedure and experimental procedures were identical to those in Experiment 1, except that instead of the fast pictures, participants were presented with words. A full counterbalancing was realized with every eight participants.

Results

As in Experiment 1, in order to reduce effects of outliers, picture naming latencies shorter than 250 ms or greater than 2500 ms and word naming latencies shorter than 150 ms or greater than 1500 ms were eliminated. Also as in Experiment 1, error rates for errors that the participant was responsible for (i.e., those excluding both mechanical errors (approximately 3.8% of the trials in all conditions) and errors where either an alternative name was given or the identity of the object was unknown (5.5% in the pure block of pictures and 8.3% in the mixed block for pictures) were uniformly low, and were therefore not analyzed.

Naming latencies were analyzed using a 2 (block type: pure vs. mixed) × 2 (stimulus type: words vs. pictures) ANOVA. In the subject analysis (F_1), both factors were within-subject factors; in the item analysis (F_2), stimulus type was a between-item factor. The mean naming latencies and percent error rates from the subject analysis are presented in Table 3.

The main effect of block type was significant, $F_1(1,63) = 40.68$, $MSe = 2045.65$; $F_2(1,158) = 88.08$, $MSe = 1225.26$. The main effect of stimulus type was also significant, $F_1(1,63) = 1010.96$, $MSe = 5417.36$; $F_2(1,158) = 498.96$, $MSe = 14262.87$ as was the interaction between these two factors, $F_1(1,63) = 24.85$, $MSe = 1256.59$; $F_2(1,158) = 27.91$, $MSe = 1225.26$. Relative to the pure blocks, words were named significantly slower in the mixed block (by 58 ms), $t_1(63) = 11.01$; $t_2(79) = 17.94$. This slowdown for the words in the mixed block was as expected. More importantly, there was a 14 ms slowdown for the pictures in the mixed block that reached significance by items, $t_1(63) = 1.61$, $p > .05$; $t_2(79) = 2.25$. Thus, unlike in Experiments 1 and 2, the results of Experiment 3 showed a clear mixing cost pattern of the sort described by Los (1996).

Experiment 4 (sums and words)

Method

Design

Experiment 4 involved a 2 (block type: pure vs. mixed) × 2 (stimulus type: words vs. sums) factorial design, with both factors being within-subject factors. Participants named words and sums in three blocks: In one block, all stimuli were addition problems (e.g., 10 + 7 = ?), in a second block, all stimuli were words, and a third block contained both types of stimuli. The dependent variables were the naming latency and error rates to the words and sums.

Participants

An additional 24 volunteer Macquarie University students participated in this experiment for course credit. All participants were native Australian-English speakers.

Materials

The experimental stimuli were 28 words and 28 addition problems. The words were all 4–5 letters long and low frequency (18–23 occurrences per 18 million based on the CELEX corpus, Baayen et al., 1993, e.g., glade, puck). The 28 addition problems were the slow problems used in Experiment 2. (As with the pictures selected for Experiment 3, these sums were selected because the results of Experiment 2 showed that their latency would decrease when they were mixed with fast stimuli.)

Apparatus and procedure

The apparatus, counterbalancing procedure and experimental procedures were identical to those of Experiment 2, except that instead of the fast problems, participants were presented with words. A full counterbalancing was realized with every eight participants.

Table 3
Mean naming latencies (RT, in ms) and percent errors (%E) in Experiment 3

Block type	Stimulus type					
	Words		Pictures		Difference	
	RT	%E	RT	%E	RT	%E
Pure	585	2.5	899	0.7	314	−1.8
Mixed	643	3.5	913	0.5	270	−3.0
Mixing effect	58	1.0	14	−0.2		

Results

Both naming latencies and percent error rates were analyzed using a 2 (block type: pure vs. mixed) × 2 (stimulus type: words vs. sums) ANOVA. In the subject analysis (F_1), both factors were within-subject factors; in the item analysis (F_2), stimulus type was a between-item factor. The mean naming latencies and percent error rates from the subject analysis are presented in Table 4.

For latency, the main effect of block type was significant, $F_1(1,23) = 11.62$, $MSe = 5557.61$; $F_2(1,54) = 11.06$, $MSe = 4164.73$. The main effect of stimulus type was also significant, $F_1(1,23) = 213.13$, $MSe = 48336.82$; $F_2(1,54) = 561.49$, $MSe = 19762.04$. The interaction between these two factors did not reach significance by subjects, $F_1(1,23) = 2.67$, $MSe = 5346.96$, $p = .12$, but was significant by items, $F_2(1,54) = 7.93$, $MSe = 4164.74$. Relative to the pure blocks, words were named significantly more slowly in the mixed block (by 76 ms), $t_1(23) = 9.93$; $t_2(27) = 13.67$. This slowdown was as expected. More importantly, the sums were also named more slowly in the mixed block (by 28 ms), although this difference was non-significant, $t_1(23) < 1.0$; $t_2(27) < 1.0$. Thus, like in Experiment 3, but unlike in Experiments 1 and 2, the results of Experiment 4 show a clear mixing cost pattern of the sort described by Los (1996).

For error rates, the main effect of block type was non-significant, $F_1(1,23) = 0.00$, $MSe = 36.55$; $F_2(1,54) = 0.00$, $MSe = 49.42$. The main effect of stimulus type was significant, $F_1(1,23) = 16.44$, $MSe = 250.30$; $F_2(1,54) = 57.26$, $MSe = 76.47$. The two factors did not interact, $F_1(1,23) = 1.55$, $MSe = 21.86$; $F_2(1,54) < 1.0$.

Discussion

The patterns observed in Experiments 3 and 4 are quite at odds with those of Experiments 1 and 2. In particular, the results of Experiments 3 and 4 showed the more typical mixing cost pattern. Words, pictures, and sums were all named more slowly in mixed blocks than in pure blocks, although the 28 ms effect for sums was not significant. These results unambiguously demonstrate that the homogenization pattern is not an inevitable effect of the naming process even when words, pictures or sums are used.

Experiments 5 and 6

As noted earlier, the fact that the mixing cost pattern did not appear in Experiments 1 and 2 (or in Lupker et al., 1997) does not cause serious problems for Los's (1996) analysis. Los's mixing cost pattern is argued to occur when there is some uncertainty as to which processing routine is going to be necessary on an upcoming trial and/or when there must be a shift of mental activities from trial to trial. When the stimuli are all words, all pictures or all sums to be named, it is quite reasonable to argue that all stimuli in the experiment, fast or slow, are processed using the same routines. If so, neither processing uncertainty nor a shifting of mental activities would play any role, allowing the impact of other aspects of processing (e.g., the actions of a time criterion) to be unveiled.

In contrast, the basic time-criterion account is challenged by the results of Experiments 3 and 4. It is silent on the issue of the qualitative nature of processing and, hence, would have no obvious way to explain why the homogenization pattern did not emerge when mixing (fast) words with (slow) pictures or sums. This certainly raises the possibility that the timing operations envisioned in the time-criterion account actually play no role except in very simple experimental situations (e.g., word, picture or sum naming).

One way to reconcile the pattern of Experiments 3 and 4 with the time-criterion account is to give processing difficulty a more central role in determining the placement of the time criterion. There clearly is an additional cost component due to the mixing of qualitatively different stimulus types such as those used in Experiments 3 and 4 (Los, 1996). One could certainly assume that this cost component acts to push up the position of the time criterion in mixed blocks, leaving it in a position at or above its position in the pure block with slow stimuli. As such, even under the assumption that a time criterion is guiding response latency in

Table 4
Mean naming latencies (RT, in ms) and percent errors (%E) in Experiment 4

Block type	Stimulus type				Difference	
	Words		Sums			
	RT	%E	RT	%E	RT	%E
Pure	444	2.1	1123	14.0	679	11.9
Mixed	520	0.9	1151	15.2	595	14.3
Mixing effect	76	−1.2	28	1.2		

Experiments 3 and 4, one would not necessarily expect the homogenization pattern. Rather, one would expect that the fast stimuli would suffer a large mixing cost while the latency for slow stimuli would be only minimally affected, the pattern observed in Experiments 3 and 4.

If this argument is correct (i.e., if responses in Experiments 3 and 4 were subject to the influence of a time criterion set at or above its position in the pure block of slow stimuli), it should be possible to get some evidence for the activity of the time criterion even in these mixed block (i.e., words and pictures, words and sums) situations. In particular, it should be possible to show that naming latencies in these mixed blocks are affected by the speed with which the other stimuli in the block are named (i.e., we should observe a homogenization-type pattern). That is the issue investigated in Experiments 5 and 6.

In Experiments 5 and 6, every block was a mixed block (pictures and words in Experiment 5; sums and words in Experiment 6). Thus, there was a (presumably, equivalent) mixing cost in all blocks in each experiment implying that the time criterion would have been set at a fairly lax position in all blocks. How the blocks differed was in terms of the ease of naming the other type of stimuli. In particular, both pictures (Experiment 5) and sums (Experiment 6) were mixed with both fast and slow words and vice versa.

If a time-criterion setting process is at work in these mixed blocks we should see an effect of word speed on picture and sum naming and vice versa. That is, the time criterion will be set lower in the condition with fast words than in the condition with the slow words and, hence, both picture and sum naming should be faster in the condition with the fast words. Similarly, there should be an impact of the speed of the pictures and sums on word naming latencies. In contrast, if the reason we did not observe the homogenization pattern in Experiments 3 and 4 is that a time criterion plays no role in more complicated mixing tasks, latencies for words, pictures, and sums should be unaffected by the speed of naming the stimuli they are mixed with.

In Experiment 5 we examined whether the speed of word naming influences picture naming latency and vice versa. Both fast and slow words and fast and slow pictures were mixed together using a within-subject design.

Experiment 5 (pictures and words)

Method

Design

Experiment 5 involved a 2 (target type: word or picture) × 2 (word speed: fast vs. slow) × 2 (picture speed: fast vs. slow) design. All factors were within-subject factors. Each participant was presented with four blocks of trials, consisting of: (1) fast pictures and fast words, (2) fast pictures and slow words, (3) slow pictures and fast words, and (4) slow pictures and slow words. The dependent variables were the naming latency and error rates for the pictures and words.

Participants

An additional 32 University of Western Ontario undergraduates participated in this experiment for course credit. All participants were native Canadian-English speakers.

Materials

Based on the results of Experiments 1 and 3, 64 fast pictures and 64 slow pictures were selected for use in this experiment. In general, these pictures were drawn from their respective fast and slow conditions in Experiment 1. However, our results in Experiment 1 suggested that some slow pictures were actually fast and vice versa. Thus, the pictures were allocated to conditions on the basis of our participants' performance rather than the results reported in Snodgrass and Yuditsky's (1996) norms. As in Experiment 1, the fast pictures differed from the slow pictures on age-of-acquisition (3.31 vs. 3.95), Kucera and Francis (1967) frequency (52.6 vs. 47.2), familiarity (3.73 vs. 3.03), image complexity (2.63 vs. 3.13), Snodgrass and Vanderwart's (1980) H (0.17 vs. 0.29), length in letters (5.12 vs. 5.45), and length in syllables (1.53 vs. 1.59), with the reported values representing the fast and slow pictures, respectively. As before, an effort was made to select sets of pictures that had similar (high) levels of name agreement (97% vs. 94% for the fast and slow pictures, respectively) in order to try to keep the error rates as low and as similar as possible for the two stimulus sets.

In addition, 64 fast words and 64 slow words were selected. Fast words were short (3- or 4-letters long), high-frequency (at least 100 occurrences per million, Kucera & Francis (1967) mean = 391), monosyllabic words (e.g., *week*, *big*); slow words were long (7- to 11-letters long), low-frequency (1–9 occurrences per million, Kucera & Francis (1967) mean = 2.90), multisyllabic words (e.g., *calibre*, *jeopardy*).

Each group of 64 words and pictures was divided into two sets, A and B, for purposes of counterbalancing. These sets were combined so that, for example, Set A of the fast words was paired with Set A of the fast pictures for one-quarter of the participants, with Set B of the fast pictures for one-quarter of the participants, with Set A of the slow pictures for one-quarter of the participants and with Set B of the slow pictures for one-quarter of the participants. The same was true for all the other sets of words and, hence, by default for all the sets of pictures.

For each block of trials, 10 practice stimuli representative of the block preceded the experimental stimuli.

Apparatus and procedure

The pairing of words and pictures created four blocks of trials (fast words/fast pictures, fast words/slow pictures, slow words/fast pictures, and slow words/slow pictures) for each participant. As in Experiment 3, participants were asked to say aloud either the word or the name of the picture as quickly as possible without making too many errors. The order of the four blocks was counterbalanced across participants so that half of the participants were presented with the fast word blocks first, and the other half were presented with the slow word blocks first. In addition, for each set of participants, the order of the fast and slow picture blocks (within the fast or slow word blocks) was also counterbalanced. Due to the fact that there were also four ways of assigning words to pictures, a full counterbalancing was realized with every 16 participants. Otherwise, the apparatus and procedure of Experiment 5 were the same as those in Experiments 1 and 3.

Results

As in Experiments 1 and 3, in order to reduce effects of outliers, latencies shorter than 250 ms or greater than 2500 ms were excluded from the picture-naming analyses. Also as before, the error rates for errors that the participant was responsible for (i.e., those excluding both mechanical errors (approximately 3.7% of the trials in all conditions) and errors where either an alternative name was given or the identity of the object was unknown (1.7% for the fast pictures and 6.2% for the slow pictures)) were uniformly low except for the slow words. Therefore, the error data were not analyzed.

The naming latencies for both pictures and words were analyzed using a 2 (picture speed) × 2 (word speed) ANOVA. In the subject analyses (F_1), both factors were within-subject factors; in the item analyses (F_2), picture speed was a between-item factor in the picture analysis whereas word speed was a between-item factor in the word analysis. The naming latencies and error rates from the subject analysis for the picture and word targets are presented in Table 5.

Targets (pictures)

The main effect of picture speed was significant, $F_1(1,31) = 222.57$, $MSe = 5408.05$; $F_2(1,126) = 122.99$, $MSe = 19502.38$. The main effect of word speed was also significant, $F_1(1,31) = 13.36$, $MSe = 4065.07$; $F_2(1,126) = 33.44$, $MSe = 4532.24$. These two factors did not interact, $F_1(1,31) < 1.0$; $F_2(1,126) < 1.0$.

Targets (words)

The main effect of word speed was significant, $F_1(1,31) = 187.15$, $MSe = 12629.80$; $F_2(1,126) = 529.34$, $MSe = 8883.60$. However, the (5 ms) effect of picture speed was non-significant, $F_1(1,31) < 1.0$; $F_2(1,126) = 1.29$, $MSe = 1361.60$. These two factors did not interact, $F_1(1,31) < 1.0$; $F_2(1,126) < 1.0$.

Discussion

The results of Experiment 5 were somewhat mixed. The results for picture targets showed clear support for the idea that a time criterion is producing a homogenization-type pattern. These targets, whether they were fast or slow to name, were named significantly faster when mixed with fast words than when mixed with slow words. In contrast, the effect for word targets was small (i.e., 5 ms) and not significant. A possible explanation for this effect being so small is that the picture speed manipulation may not have been particularly strong. Note that the latency difference between the fast and slow pictures was about 100 ms less than the latency difference between the fast and slow words. Thus, the pull exerted on the word naming latencies as a function of picture speed would have been somewhat less than the pull exerted on picture naming latencies as a function of word speed. In Experiment 6, we re-examined the question of whether word naming latencies are affected by the speed of naming the other stimuli in the block using a more powerful manipulation.

Table 5
Mean naming latencies (RT, in ms) and percent errors (%E) in Experiment 5

Filler type	Fast		Slow		Filler effect	
	RT	%E	RT	%E	RT	%E
Picture targets						
Fast	790	0.3	836	0.2	46	−0.1
Slow	989	1.0	1025	0.3	36	−0.7
Word targets						
Fast	548	0.3	553	0.4	5	0.1
Slow	820	4.5	825	4.7	5	0.2

Experiment 6 (sums and words)

In Experiment 6 we examined both the question of whether the speed of word naming affects the latency for naming sums and of whether the speed of sum naming affects the latency for naming words. In this experiment, a block always contained sums and words, hence the mixing costs were, presumably, held constant. Because there are a limited number of sums that can be used (in comparison to the number of available pictures), the design of this experiment was slightly different from that of Experiment 5. Word speed and sum speed were not factorially manipulated. Instead, in one condition, target words were mixed with either fast sums or slow sums (the "fillers"). In the other condition, target sums were mixed with either fast words or slow words (the "fillers"). (In addition, target type was manipulated between-subjects.) If a time criterion is at work here, then an effect of filler speed should be found in both conditions.

Method

Design

Experiment 6 involved a 2 (target type: words or sums) × 2 (filler speed: fast vs. slow) factorial design. Target type was a between-subject factor and filler speed was a within-subject factor. The critical dependent variables were the naming latency and error rates to the targets.

Participants

An additional 60 volunteer Macquarie University students participated in this experiment, 24 in the word target condition and 36 in the sum target condition. All participants were native Australian-English speakers.

Materials

The word targets were the same 28 words used in Experiment 4. The filler items for the word target condition were the fast and slow addition problems used in Experiment 2.

The sum targets were the 28 fast addition problems used in Experiments 2 and 4. The fast problems were chosen as the stimuli in this experiment because the naming latencies for their solutions were more similar to word naming latencies than the latencies for the solutions of slow addition problems (which were over 1000 ms). The filler words for the sum target condition were selected to be either fast or slow. As in Experiment 5, the fast words were short (3- or 4-letters long), high-frequency (at least 100 occurrences per million, Kucera & Francis (1967) mean = 298), monosyllabic words (e.g., *week*, *big*); the slow words were long (7- to 11-letters long), low-frequency (1–6 occurrences per million, Kucera & Francis (1967) mean = 2.43), multisyllabic words (e.g., *calibre*, *jeopardy*).

For both word and sum targets, the target items were divided into two matching sets, A and B. The assignment of the sets to the fast and slow filler blocks was counterbalanced across participants so that each participant saw a target item only once, and across every pair of participants each target occurred once in the fast filler block and once in the slow filler block.

Apparatus and procedure

The apparatus and general procedure were identical to those of Experiments 2 and 4. Participants were presented with a fast block and a slow block, and asked to say aloud either the word or the solution to the problem as soon as possible. The order of fast and slow filler blocks was counterbalanced across participants so that half of the participants were presented with the fast filler block first, and the other half were presented with the slow filler block first. A full counterbalancing was realized with every four participants.

Results

The naming latencies for sum and word fillers were analyzed using a 2 (filler type) × 2 (filler speed) ANOVA. In the subject analysis (F_1), filler type was a between-subject factor and filler speed was a within-subject factor. In the item analyses (F_2), both factors were between-item factors. The mean latencies and error rates to the targets and the fillers from the subject analysis are presented in Table 6.

Targets

In terms of target latencies, as expected, there was a main effect of target type $F_1(1, 58) = 6.91$, $MSe = 14723.50$; $F_2(1, 54) = 28.66$, $MSe = 3473.38$. Words were named faster than sums. More importantly, there was a main effect of filler speed $F_1(1, 58) = 7.71$, $MSe = 1672.39$;

Table 6
Mean naming latencies (RT, in ms) and percent errors (%E) in Experiment 6

Filler type	Fast		Slow		Filler effect	
	RT	%E	RT	%E	RT	%E
Word targets	532	0.6	557	0.3	25	−0.3
Sum targets	595	0.8	612	0	17	−0.8

$F_2(1, 54) = 9.17$, $MSe = 1223.45$. Both words and sums were named more rapidly when the fillers were fast than when they were slow. There was no interaction $F_1(1, 58) < 1.0$; $F_2(1, 54) < 1.0$. In terms of target errors, there were no significant effects, all Fs < 3.0.

Fillers

In terms of filler latencies, there was a main effect of filler type $F_1(1, 58) = 83.48$, $MSe = 31947.86$; $F_2(1, 108) = 206.43$, $MSe = 8663.77$. Word fillers were named more rapidly than sum fillers. There was also a main effect of filler speed, $F_1(1, 58) = 217.39$, $MSe = 14767.76$; $F_2(1, 108) = 316.01$, $MSe = 8663.77$. Fast fillers were named more rapidly than slow fillers. There was also a significant filler type by filler speed interaction $F_1(1, 58) = 35.83$, $MSe = 14767.76$; $F_2(1,108) = 46.80$, $MSe = 8663.77$ due to the fact that the speed manipulation was stronger with the sum fillers (1104 ms for the slow sums, 635 ms for the fast sums) than with the word fillers (703 ms for the slow words, 505 ms for the fast words). In terms of filler errors, the only significant effect was the effect of filler type $F_1(1, 58) = 56.72$, $MSe = 86.35$; $F_2(1, 108) = 46.12$, $MSe = 102.35$. The error rate was higher with the sums (14.1%) than with the words (1.1%).

Discussion

In Experiment 6, both word and sum targets showed the expected effects. That is, words were named more rapidly when mixed with fast sums than when mixed with slow sums and sums were named more rapidly when mixed with fast words than when mixed with slow words. These results, then, substantiate the claim that operations like those described in the time-criterion account are at work even when the two stimulus types require qualitatively different processing routines.

Note that the (sum) speed manipulation for word targets in Experiment 6 (a 469-ms difference between the fast and slow sums) was substantially larger than the (picture) speed manipulation for word targets in Experiment 5 (a 194-ms difference between the fast and slow pictures). Thus, it follows that the effect on word naming latencies was noticeably greater in Experiment 6 (25 ms) than in Experiment 5 (5 ms). What should also be noted here, however, is that the size of the speed manipulation is not always perfectly predictive of the size of the effect on latencies. The (word) speed manipulation for sum targets in Experiment 6 (198 ms) was very similar to the (picture) speed manipulation for word targets in Experiment 5. Yet, a significant 17-ms effect was observed for sum targets in Experiment 6 while, as noted, the effect for word targets in Experiment 5 was a non-significant 5 ms. Further, the largest effect of all, the effect for picture targets in Experiment 5 (41 ms) was obtained with a (word) speed manipulation of 272 ms, which is noticeably smaller than the (sum) speed manipulation in Experiment 6.

One way of thinking about these patterns is to note that word filler speed appears to affect picture target latencies much more than picture filler speed affects word target latencies whereas the effects tend to be slightly more symmetric with words and sums. Thus, a possible implication is that there is a processing asymmetry between words and pictures that does not exist between words and sums. Alternatively, it is possible that this asymmetry is an effect of the variability in latencies within the stimulus sets. That is, there was, inevitably, substantially more variability within a condition (e.g., the slow picture condition) in the picture-naming task than in word or sum naming. Thus, it may be that the slower pictures in the fast picture condition and the faster pictures in the slow picture condition cause the picture speed manipulation to be much less effective than the means of the two conditions would suggest. Although it is not possible to disambiguate these ideas based on the present data, there is evidence reported elsewhere (Bodner & Masson, 2001) that variability within a condition can have a marked effect on the willingness of participants to adopt various processing strategies.

General discussion

A consistent finding in the cognitive literature is that when two conditions are presented in a mixed block, there is a mixing cost. That is, both conditions produce longer latencies in mixed blocks than in pure blocks, although the impact is often much larger in the easier condition than in the more difficult condition (Los, 1996). In contrast, Lupker and colleagues (Desrochers et al., 2003; Lupker et al., 1997; Taylor & Lupker, 2001) have reported a different pattern when words of different types are mixed in naming tasks. In these experiments, a homogenization of latencies is found in that the faster stimuli have longer latencies in mixed blocks whereas the slower stimuli have shorter latencies in mixed blocks. One goal of the present investigation was to begin to reconcile these contradictory patterns of results.

In Experiments 1 and 2, it was demonstrated that the homogenization pattern occurs when other types of stimuli, in particular, pictures and sums, are named. Thus, this pattern is not restricted to word stimuli. In Experiments 3 and 4, it was demonstrated that the mixing cost pattern emerges when mixing word, picture and sum stimuli in a naming task. Thus, the homogenization pattern does not emerge simply because the task is a naming task (or because these particular types of stimuli are used). In Experiment 5 and 6, it was demonstrated that the latencies for words, pictures and sums can show a homogenization-type pattern when mixed together as long as the mixing costs due to preparation uncertainty and shifting mental activities do not differentially affect the different blocks of trials.

The present results are then consistent with both Los's (1996) claims and Lupker and colleagues' (Chateau & Lupker, 2003; Kinoshita & Lupker, 2003; Lupker et al., 1997; Taylor & Lupker, 2001) time-criterion account. In many ways, this should not be a surprising conclusion. Theories about changes in the nature of processing (Los, 1996) and theories about changes in the speed of processing/responding (Kello & Plaut, 2000; Lupker et al., 1997) are certainly not mutually exclusive. Instead, it makes sense that both mechanisms are at work: When certain types of stimuli are mixed and problems are created due to preparation uncertainty and shifting mental activities, presumably, the position of the time criterion would be set to reflect that fact. As such, there would be no reason to expect the homogenization pattern in such circumstances even though a time criterion may, nonetheless, play a major role in determining response latency.

The question still exists, however, of what actually determines which type of mixing pattern will emerge whenever a mixed block design is employed. One obvious possibility is that there will be a homogenization pattern when stimuli requiring the same processing routine are mixed whereas there will be a mixing cost pattern when stimuli requiring qualitatively different processing routines, or stimuli on which different tasks must be performed, are mixed. In general, this statement does characterize the literature, however, there are some clear exceptions. For example, Grice and Hunter (1964) and Sanders (1977) have reported a mixing cost pattern when mixing tones of two intensities in a simple tone detection task (see also Niemi, 1991, for a similar demonstration using lights). It seems somewhat unlikely that loud and soft tones, or bright and dim lights require different processing routines. On the other side of the coin, Strayer and Kramer (1994a, 1994b) have demonstrated the homogenization pattern when mixing varied and consistent mapping trials in a visual/memory search paradigm. While the stimuli were essentially the same in the two situations (i.e., letters), the nature of the search (controlled vs. automatic) would have been different in the two situations, presumably requiring qualitatively different processing routines. Thus, while it would be a reasonable generalization to say that what determines which of the two patterns will emerge is whether the two conditions require qualitatively different processing routines or not, the issue is clearly more complicated than that.

A potential explanation for some failures to observe the homogenization pattern when the stimuli do not appear to require qualitatively different processing routines could be, as Kiger and Glass (1981) suggested, that, in the mixed blocks, the harder of the two stimuli/tasks often controls the relevant criterion. For example, Gordon (1983) and Glanzer and Ehrenreich (1979) have shown an asymmetric mixing cost pattern when mixing high and low frequency words in a lexical decision task (LDT) (i.e., latencies for high frequency words are longer in mixed blocks whereas latencies for low frequency words are essentially the same in pure and mixed blocks). The explanation would be that, in LDT, it may not be possible for participants to respond to the low frequency words much faster than they do in pure low frequency blocks without too much being sacrificed in terms of error rate. Thus, the time criterion in mixed blocks would be placed essentially at the same position that it is in pure low frequency blocks (and much above where it is in pure high frequency blocks). If so, an asymmetric mixing cost pattern would emerge in tasks like LDT, although for a different reason than that proposed by Los (1996).

Where the naming task differs from LDT (and many other tasks) is that the relationship between latencies and error rates in naming is not quite as direct as that relationship in many other tasks. For example, decreases in naming latencies, produced through the use of a deadline procedure (e.g., Colombo & Tabossi, 1992; Kello & Plaut, 2000), often do not lead to any increases in error rates. The implication is that, in standard naming tasks, participants have a pretty good idea of what the correct response is well before they actually produce it. This situation allows for considerable flexibility in the position of any criterion even when hard stimuli are involved. As such, the position of that criterion in mixed blocks need not be controlled by the harder stimuli but, instead, can be affected by the entire set of stimuli, producing the homogenization pattern. Whether this difference between naming and LDT will ultimately provide the basis for an adequate explanation of the different mixing patterns in the two tasks is, clearly, an issue for future research.

Time-criterion vs. input gain

As noted previously, Kello and Plaut (2000, 2003) have proposed an alternative to the time-criterion account. Their notion is that what is adjusted from block to block is the rate of processing. When the stimuli are all difficult to process (e.g., in a pure block of slow stimuli), processing is slowed to keep the error rate under control. When the stimuli are all easy to process (e.g., in a pure block of fast stimuli), processing can be sped up with little threat of error. Mixed blocks would invoke an intermediate processing rate.

A reasonable question is whether the input gain account could derive an acceptable explanation of the effects reported here, particularly, those effects which seem amenable to a time-criterion account. Experiments 1 and 2, which parallel all the experiments using the word-naming task, could be easily explained in terms of input gain, once one has developed a workable model of the picture and sum naming processes. That is, whatever processes are involved in naming pictures or naming sums would be sped up or slowed down due to adjustments in the input gain, producing the homogenization pattern.

The situation becomes a bit more difficult when one considers the other experiments. To begin with, in order to allow cross-stimulus effects, one must assume either: (1) that any adjustments to the input gain (as a function of, for example, the difficulty of the word-naming task) are made essentially across the entire processing system or (b) that words and pictures or words and sums share a number of processing structures such that changing the input gain for the structures relevant to word processing would also change the input gain for a number of structures relevant to picture or sum processing.

Making the former assumption (i.e., that there is a system-wide adjustment) would be a fairly straightforward approach. Making the latter assumption would not. Implementing a system that ties the input gain account to models of the temporal dynamics of picture naming and sum naming and then linking those models to Kello and Plaut's (2003) word naming model would be far from a simple task. As Kello and Plaut noted, even when considering only the word-naming task, the nature of the model itself is a crucial determinant of whether the input gain account can explain the relevant data (i.e., Lupker et al.'s (1997) results and the results from their own tempo-naming experiments). Thus, it would be impossible to tell, without considerable modelling work being done, whether a change in the input gain parameter for the processing structures for a particular task would noticeably affect the latency in other tasks that share a few of those processing structures. As such, let us adopt the assumption that adjustments to input gain are made essentially across the entire system.

With respect to Experiments 3 and 4, if one assumes that pictures/sum processing is harder than word processing, the input gain account would have the same problem explaining the results as the time-criterion account does. One important difference between the two accounts, however, is that although the time-criterion account is a speed-based account, the input gain account is a difficulty-based account with the "difficulty" (of processing any particular stimulus) being defined strictly within the context of the particular task. As a result, the fact that picture/sum naming latencies are longer than word naming latencies cannot be presumed to mean that picture and sum naming are more "difficult" than word naming. It is possible that, given the pictures and words used in Experiment 3, either word naming or picture naming might actually have been more "difficult" or they could have been equivalently difficult. The settings of the input gain would be based on those difficulty levels, meaning that the input gain may have been set higher, lower or the same when words were mixed with either pictures or sums in comparison to the those settings in pure blocks.

Although this fact about the input gain account gives that account more flexibility, it does not appear to provide a way for the account to explain the data of Experiments 3 and 4. Specifically, the fact that words were slower in the mixed blocks than in the pure blocks implies that the input gain had a higher setting in the pure word block than in the mixed block. That fact would suggest that both picture naming and sum naming were indeed, relatively more difficult than word naming. What that should mean, however, is that the input gain would have been set even lower in the pure picture- or pure sum-naming block. Thus, one would expect to have seen longer latencies in those blocks. As noted, if anything, the latencies were slightly shorter in the pure picture- and pure sum-naming blocks. Thus, it would seem that this account, without incorporating Los's (1996) ideas, would have the same difficulty with the results of Experiments 3 and 4 that the basic time-criterion account does.

The input gain account, like the time-criterion account, would have much better success with the results of Experiments 5 and 6. When considering only a single task, processing speed should be a good measure of processing difficulty. Thus, fast words/pictures/sums are easier than slow words/pictures/sums and, hence, should allow an increase in the *system-wide* input gain. As such, naming of the other type of stimuli should benefit from using fast, rather than slow, words, pictures, or sums, just as observed in Experiments 5 and 6 (we are assuming again, of course, that a workable model of all these processes can be developed).[2]

[2] In Kello and Plaut (2000), there was considerable discussion about the usefulness of naming durations for distinguishing between the time-criterion account, which is silent on this matter, and the input gain account, which can predict that duration effects should mirror homogenization effects whenever homogenization effects appear. In the present Experiment 2, naming durations were measured and no effects were observed in spite of the large homogenization effects. However, because the occurrence of duration effects is not actually regarded as a prediction of the input gain account, but merely a potential byproduct of input gain adjustment (C. Kello, personal communication, November, 2002), this issue was not pursued further. (See also Kello et al., 2000 and Damian, 2003, for a further discussion of the duration issue.)

Modelling the workings of the time-criterion

In contrast to the input gain account, which needs to be tied to a specific model of the processes of interest, the time criterion is viewed as a parameter that is general across any reaction time (RT) task and across different stimulus types. Its function is to control latencies within a particular context (i.e., a trial block) and it is set in response to both the global context (e.g., experimental instructions, the processing demands of task switching) and the local context (e.g., the latencies of the most recent stimuli). As such, it is quite a different mechanism than many of the mechanisms that have been proposed to explain the effects of pure vs. mixed blocks in the literature (e.g., Meyer et al., 2003; Monsell et al., 1992; Zevin & Balota, 2000). However, the precise workings of the time-criterion account are not yet fully specified. For example, the account is presently silent with regards to how to explain the latency difference that remains between fast and slow items in a mixed block, especially when that difference is as large as it is when mixing words and pictures or words and sums. If a single time criterion were used in a mixed block, the latency difference between these stimuli should be much smaller than it is.[3]

Taylor and Lupker (2001) recognized this problem and suggested that the time criterion should not be viewed as a fixed deadline, but rather a flexible one. As noted above, they also suggested that respondents in a RT task must also use some sort of quality criterion. The idea is that if the response quality does not meet this criterion, the response is not initiated even though the time criterion has been reached. This idea would explain why a latency difference between fast and slow items is still observed in a mixed block. The more central question is exactly how contributions of the time criterion and quality criterion combine to produce an observed latency.

One avenue that appears promising is to borrow a notion suggested independently by Mozer, Colagrosso, and Huber (2002). Their main idea is that instead of simply choosing a threshold in error rate (reflecting the position of a quality criterion) or in RT (time criterion), a response cost is computed based on both RT (i.e., the cost of waiting) and error rate (i.e., the likelihood of making an incorrect response), and that a control mechanism initiates a response at the point in time when a minimum in cost is attained. The error cost may be reasonably assumed to decrease monotonically over time (because accuracy increases over time). The RT cost (the cost associated with delaying a response) could be assumed to increase linearly over time. Within Mozer et al.'s framework, the model cannot compute the error cost without knowing what the correct response is, hence the error cost term used to compute the response cost will be based on the model's current estimate of the likelihood of each alternative response. The effect of stimulus difficulty on the current trial will be reflected in this component, and hence a latency difference between different stimulus types (e.g., high and low frequency words) will still be observed in a mixed block.

Tying these ideas to the notion of a moveable time criterion would require assuming only that the nature of the response cost function varies (due to changes in the error cost function, the RT cost function or the way in which the two functions are combined) as a function of the difficulty of naming the other stimuli in the trial block. Further, because the error cost and RT cost are concepts that are not tied to a specific task, an account based on these concepts should have no serious difficulties explaining cross-task (i.e., word and picture naming) effects. Admittedly, these are very preliminary ideas. However, we do believe that they have some promise and we are currently working with them in order to better develop the time-criterion account.

Conclusions

In the present research, we used words, pictures, and sums as stimuli in order to more closely examine the bases for two different data patterns reported in the cognition literature, the homogenization pattern (Lupker et al., 1997), and the mixing cost pattern (Los, 1996) and to examine the theoretical positions that have emerged from these two patterns. Results indicate that the occurrence of these patterns is not tied to a particular stimulus type or a particular task. Equally importantly, these data are quite consistent with the argument that the theoretical mechanisms that are presumed to underlie both of these patterns are active in all situations. Thus, which pattern emerges will be a function of which mechanism plays the greater role in the particular task.

[3] An alternative would be to assume that when two qualitatively different stimulus types are named, separate time-criteria are employed for each. In fact, one could certainly argue that this would be rational thing for participants to do when naming, for example, words and pictures in a mixed block. Unfortunately, making this assumption would not solve the general problem of explaining why there is a latency difference between *qualitatively identical* stimuli, like high and low frequency words, in mixed blocks. Further, if there were separate time criteria for, for example, words and pictures, it would raise the additional question of why cross-stimulus effects, like those in Experiments 5 and 6, were observed.

Appendix. Picture stimuli in Experiment 1

Fast pictures	Slow pictures
Apple[b]	Alligator[a]
Ball[c]	Arm[c]
Balloon[a,b]	Arrow[a,b]
Banana[a,b]	Ashtray
Basket[b]	Axe[a,c]
Bed[b]	Barrel[b]
Bell[b]	Bear
Belt[a,b]	Bird[a,c]
Bicycle	Bottle[a,b]
Book[b]	Camel[a,c]
Boot[a,b]	Cap
Bowl[b]	Chain[a,c]
Box[a,c]	Church[a,c]
Bus[a,c]	Cigar
Butterfly[b]	Cigarette[a,c]
Candle[b]	Clown[a,c]
Carrot[b]	Cow[a,c]
Cat[a]	Crown[a,c]
Chair[b]	Desk[a,c]
Clock[a,b]	Donkey[a]
Comb[b]	Doorknob[a,c]
Cup[b]	Dress[c]
Dog[b]	Drum[a,c]
Door[a,b]	Duck[c]
Ear[a,b]	Guitar[a,b]
Elephant[a,b]	Hair[c]
Envelope[a,b]	Harp[c]
Eye[b]	Kangaroo[b]
Fish[b]	Knife[b]
Flag[b]	Lemon[a,c]
Flower[b]	Lion[a,c]
Foot[b]	Lobster[c]
Fork[b]	Lock[a,c]
Frog[b]	Monkey[a,c]
Giraffe[a,b]	Onion[a,c]
Glass	Ostrich[a,c]
Grapes[a]	Owl[a,c]
Hammer[a,c]	Peanut[a,c]
Hand[b]	Penguin[a,c]
Hanger	Pig[a,b]
Hat[b]	Pineapple[a,c]
Heart[b]	Pipe[a,c]
Helicopter[b]	Plug[c]
House[b]	Potato[a,c]
Iron[a,c]	Pumpkin[a,b]
Key[b]	Refrigerator
Kite[a,b]	Ring[a,c]
Ladder[a,b]	Sailboat
Lamp[a]	Sandwich[a,b]
Leaf[b]	Saw[a,c]
Lips	Screw[c]
Motorcycle[a,c]	Screwdriver[a,c]
Mountain[a,c]	Seal
Mushroom[b]	Shirt[a,c]
Nose[a,b]	Skirt
Pants[b]	Skunk[c]
Pear	Sled
Pen[b]	Snail[a,c]
Pencil[b]	Spider[c]
Rabbit[a,c]	Squirrel[a,c]
Ruler[b]	Stool[a]
Scissors[b]	Strawberry[a,c]
Shoe[a,b]	Swan[c]
Snake[a,c]	Swing[a,c]
Snowman[a,c]	Thumb[a]
Sock[b]	Tiger[a,c]
Spoon[b]	Toaster[a,c]
Star[b]	Tomato[a,c]
Sun[b]	Toothbrush[a,c]
Table[a]	Train[a,c]
Telephone	Truck[a,c]
Tree[b]	Vase[a,c]
Umbrella[b]	Vest[a,c]
Watch[b]	Violin
Well[a,c]	Watermelon[c]
Wheel[a,c]	Whistle[a,b]

[a] Also used in Experiment 3.
[b] Used as a fast picture in Experiment 5.
[c] Used as a slow picture in Experiment 5.

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