Sensory Overlap for Specific Memories Only Matters for Poor Memory Traces

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ABSTRACT

Similar events may reduce the likelihood of the cognitive system to accurately remember a specific memory. Similarity leads to overlap between mnemonic traces, which, in turn, interferes with the discrimination of the traces. Therefore, it is important to determine how and when overlapping is detrimental to the discrimination between the traces. According to the Act-In memory model, the specificity of a memory trace is determined by the sensory overlap as well as by the number of participating sensory modalities on which overlap occurs (unimodal vs. multimodal). Increasing overlap should only be critical when the memory traces are the most difficult to discriminate from each other, which is more likely for unimodal than multimodal traces. As such, multimodal events might be more efficient than unimodal events to allow memory specificity. In two experiments, participants had to reproduce visuospatial sequences in a 2 × 2 matrix. The level of sensory overlap (high vs. low) and the number of components on which overlap occurs in the memory traces (unimodal vs. multimodal-discrimination) were manipulated. The results showed that memory span was lower when the visual overlap was at its highest, but more significantly, when trace discrimination was unimodal (Experiments 1 and 2). Moreover, for visually richer stimuli, visual overlap was shown to be detrimental to specific memory only in a condition of visual degradation. Taken together, the results suggest that the sensory overlap is essentially critical to specific memory when it is at its highest, which is the most likely for low richness unimodal stimuli.

OPEN DATA

KEYWORDS

specific memory
accuracy
memory discrimination
sensory degradation
trace overlapping

INTRODUCTION

Memory is a constructive and dynamic process. As such, memory is not a simple retrieval of an event, but rather a (re)construction (emergence) of knowledge based on previous experiences (e.g., Schacter, 2012). Accordingly, efficient memory could be characterized not only by the number of items retrieved, but also by the accuracy of recall (Koriat et al., 2000). Accuracy is the degree of matching between the retrieved event and the real event, but it also reflects the quality of information recalled (e.g., number of details, vividness). It is necessary to determine how to improve the accuracy of memory recall, and to this aim, to understand which factors are involved. Specificity appears as a crucial factor for accuracy (Greene & Naveh-Benjamin, 2020; Korkki et al., 2020). According to the principle of specificity (Surprenant & Neath, 2009), accuracy on memory tasks is likely to be worse (due to forgetfulness, memory errors) as the task requires an individual to retrieve increasingly specific information (see also the fuzzy trace theory, Reyna & Brainerd, 1995). For instance, the memory of a matrix of squares might be retrieved with high specificity ("there was a red square at the top left"), with less specificity ("there was a red square somewhere in the matrix"), or only based on a fuzzy representation ("there was a colored square somewhere in the matrix"). As such, the more the task requires accurate recall, the more crucial the access to specific knowledge. The specificity might be intrinsic to the event (the overlap between the traces encoding the events) or to the task (the extent to which the task requires access to specific details), but it should also depend on the amount of memory traces (re)activated.

According to the Activation-Integration model (Act-In, Versace et al., 2009, 2014), a memory emerges from the final state of the dynamic of activation of previous memory traces constrained by the current situation (e.g., task requirements, individual's goal). The number of activated traces depends on the overlap (similarity) of the traces in the system. When numerous memory traces are activated, the resulting knowledge is unspecific (i.e., it is common to many events) whereas the activation of one (or a very limited number of) trace allows keeping the details in the emerging representation (see Hintzman, 1986). Thus, the more the system reduces the activation to a limited number of traces

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based on trace discrimination, the more specific the emerging representation will be and the more details will be accessed. In other words, the more specific the representation, the more it represents a given event without including details of other events. For instance, when an individual learns a list of semantically highly associated items (high semantic overlap), the subsequent presentation of an item during recognition will produce a large diffusion of activation to the other items on the list (high probability of activating semantic associates). Such a large diffusion should reduce the possibility of activating specific details of the study items (only the common elements remain) and thus reduce the accuracy of memory. When the task requires a high degree of specificity, for instance, when a critical lure (i.e., a new item highly associated with the to-be-learned list) is presented, the likelihood of falsely recognizing it increases dramatically (Roediger & McDermott, 1995). Conversely, items with low semantic overlap should restrain the diffusion of activation of other members of the list, leading to correctly rejecting the lure (Roediger et al., 2001). Consequently, low overlap of memory traces promotes the emergence of specific knowledge required for an accurate memory because memory traces are more discriminated from each other (Surprenant & Neath, 2009).

In the Act-In model of embodied cognition, memory traces are defined as grounded in the sensory (and motor) components of the event (see Noppeney, 2009; Vallet et al., 2013). Sensory modalities are then at the core of knowledge and thus crucial to specificity. When the task relies on unimodal stimuli (e.g., all visual), the cognitive system can only discriminate traces based on their visual components (unimodal discrimination). Unimodal discrimination refers to the potentiality of the system to distinguish traces on a unique modality. If they are very similar, their components should highly overlap, making it difficult for the system to produce specific knowledge. Instead, when the memory task involves multimodal stimuli (e.g., audiovisual), then the different traces can be discriminated based on both visual and auditory components (multimodal discrimination). Multimodal discrimination refers to the potentiality of the system to distinguish traces on several modalities. When the stimuli are similar to each other on the visual components, the cognitive system may still be able to produce specific knowledge if the overlap in auditory components is minimal. In other words, the overlap between the memory traces is reduced when the stimuli are multimodal increasing the capacity of memory to produce specific knowledge.

Consistent with the principle of specificity (Surprenant & Neath, 2009), access to specific representation should especially be critical when a memory task requires high accuracy. In unimodal situations, the similarity/overlap of auditory (Baddeley, 1966; Conrad, 1964) or visual (Avons, 1999) stimuli reduces serial recall, which requires greater accuracy (identity and order of the items, see also Jalbert et al., 2008, for a similar result for the recall of spatial location). In tasks that do not require a very detailed memory, unimodal overlap of stimuli impacts performance to a lesser extent, since free recall (without concern for intrusions) or recognition tasks (without concern for lure rejection) need only the retrieval of the identity of the item, not the order (Avons, 1999). In these tasks, the overlap is less detrimental because the details of the memory are not assessed.

The specificity of the traces could be increased by making them richer. Indeed, participants can differentiate between an image of a new door and previously studied doors with about 85% accuracy after studying 400 different doors with their backgrounds. However, it is not the presentation of the doors themselves that is at the origin of this high performance, but rather the conjunction of the doors with their surrounding background as performance decreased by 20% when the background was removed (Vogt & Madnussen, 2007). The context leads to richer traces that reduce overlapping and thus increase memory performances. Similarly, in the picture superiority effect (Paivio & Csapo, 1973), better memory performance for pictures than for words is generally explained by the addition of visual features to a concept (Roediger & Weldon, 1987). Yet, this effect could be reversed by decreasing the visual overlap of the words and increasing that of the pictures (Ensor et al., 2019). Consequently, the picture superiority effect might result from a unimodal discrimination boost. The richness of the memory traces could also be found in the dual-coding effects (Paivio, 1971, 2007), which states adding a modality (e.g., visual imagery) to a verbal encoding increases memory recall. When participants read words aloud as opposed to silently (production effect; Hopkins & Edwards, 1972; Jamieson et al., 2016) or enact the action described in a sentence ("peeling a banana") during learning (enactment effect; Engelkamp & Zimmer, 1984; Plancher et al., 2018), then better specific memory performance is observed[1]. However, and as predicted by Act-In, the verbal modality is not important compared to the multimodal encoding situation. The benefit could result from the reduction of the overlap between the traces through enrichment of the trace by adding a modality. As such, multimodal stimuli increase visual recognition (see Matusz et al., 2017). Similarly, Saults and Cowan (2007) found that memory for audiovisual stimuli can be greater than for modality-specific stimuli in working memory (see also Guérard et al., 2009). Thus, multimodal discrimination allows for improving memory performance by reducing the number of traces activated at test. Increasing the number of modalities involved in a given trace should then increase the likelihood of finding a specific combination of components (reduced overlap) and, therefore, make it easier to reduce the number of traces activated during the emergence of knowledge.

To summarize, (a) the ability of a specific representation to emerge requires a discrimination mechanism in order to reduce activation to few traces and is more critical for tasks that require accurate recall, (b) the ability of the system to reduce activation to few traces should be facilitated when traces have low overlap between them, and (c) the specificity of traces is increased when the overlap between components is low and even more so when traces are enriched, for instance, using multiple modalities (see, Brunel et al., 2013). Surprisingly, no study seems to have explored the interplay between the sensory overlap of trace components and the number of components in the trace in a specific memory.

Therefore, it seems particularly relevant to study how and when sensory overlap is involved in memory. Given that overlap is less critical when the system is already able to discriminate traces, the question is rather to determine how and when increased unimodal and multimodal overlap impairs memory accuracy. Consistent with the principle of specificity (Surprenant & Neath, 2009), overlap should be particularly involved when access to specific knowledge is critical, as in serial reconstruction tasks (both identity and order reconstruction). The increase of overlap should be particularly critical in these tasks when memory traces are the most difficult to discriminate between, such as when the stimulation is unimodal and the stimuli are very basic (i.e., not rich). On the other hand, when memory traces are easier to discriminate, as with multimodal stimulation, the degree of overlap on each modality should not impact performance. We predicted that the specificity of multimodal traces should not rely on the level of overlap. Conversely, since unimodal traces are more likely to suffer from overlap, the level of overlap should directly modulate serial reconstruction performance.

THE CURRENT STUDY

The current study aimed at identifying when increased sensory overlap impairs the serial reconstruction performance depending on whether the trace can be discriminated on one (unimodal discrimination) or several components (multimodal discrimination). To test this, two experiments were conducted to examine the interplay between the level of overlap (low vs. high) and the number of discrimination components (unimodal vs. multimodal discrimination). As some results of the first experiment could be interpreted by the use of a specific dual-coding strategy (Paivio, 2007), Experiment 1B served as a control of Experiment 1A. Experiment 2 was then proposed to clarify the mechanisms underlying sensory multimodal discrimination in comparison to trace richness.

The experiments were designed based on an adaptation of the classical Simon task for use as a memory span paradigm (Humes & Floyd, 2005; Pisoni & Cleary, 2004). In the Simon task, four tiles are presented in a 2 × 2 matrix and associated with four different colors and four different sounds. The tiles are activated (light and sound played) one after the other and participants have to press the corresponding tiles in the right order to reproduce the sequence (length of N). When participants correctly reproduce the sequence, a new sequence of length N+1 is presented. The dependent variable corresponds to the longest sequence that a participant can reproduce correctly (memory span). In this adaptation, the association between location and colors/sounds is changed in each sequence to avoid long-term learning. This task was chosen for three reasons. First, the repetition of the items within a sequence should maximize the overlapping (activation of a greater number of traces) between the basic multimodal (here, audiovisual) stimuli (color and tones) because they could be used multiple times in a trial. A given sequence is thought to correspond to a specific memory because it involves accurately reconstructing the items and the order in which they appeared in the sequence. As such, this task may be particularly relevant to studying sensory overlap. Second, this task makes it easy to manipulate the level of overlap (low vs. high) and to vary the sensory modality of the memory traces (visual, auditory, or audiovisual). In other words, this paradigm allows manipulating the sensory overlapping of the traces within each spatial sequence. Third, the Simon task allows for dissociating the task requirement from the sensory overlap manipulation, as the responses are based on the reproduction of spatial sequences (which were not manipulated here). In other words, the task is related to the spatial sequence and not to the content of the tiles.

EXPERIMENT 1A

Experiment 1A aimed to assess the interplay between the level of sensory overlap (low vs. high) and the number of discrimination components (visual, auditory, or audiovisual) in the Simon task. Since the Simon task is a visuospatial task based on audiovisual stimuli, it is necessary to determine whether one of the two sensory modalities drives performance on the task in addition to the spatial component. As such, a second objective was to determine which sensory component drives performance on the task, as it might be expected that the manipulation of overlap would only be crucial for this modality (Surprenant & Neath, 2009).

To differentiate a basic effect of multimodal stimulation (potential attention boost, Spence & Santangelo, 2009) from that of a facilitation of trace discrimination due to the number of sensory modalities, all the stimuli were bimodal (both visual and auditory), but the overlap was based manipulating a given modality discrimination (visual, auditory, or audiovisual). More precisely, for the visual unimodal discrimination condition, while all the visual stimuli were different and specific (4 colors), they were all presented with the same sound (no specific auditory feature). Similarly, for the auditory unimodal discrimination condition, all the auditory stimuli were different and specific (4 tones), but all were associated with the same color (no specific visual feature). Finally, in the audiovisual discrimination condition, all the visual and auditory stimuli were different and specific (4 colors associated with 4 tones). To summarize, all the presentations were bimodal, but the discrimination was either unimodal (visual or auditory unimodal discrimination conditions) or both visual and auditory (audiovisual discrimination condition). Given that the audiovisual discrimination condition is less likely to generate an overlap of the memory traces, it was predicted that the overlap should not affect memory span, unlike the unimodal discrimination condition. In the latter condition, the overlap of the memory traces was expected to be high, thus decreasing memory performance in the high overlap condition compared to the low overlap condition. In addition, the visual modality was expected to drive the Simon task performance, since the task has a spatial component for which the spatialization of the visual signals may help, contrary to auditory signals (see the unity assumption principle, Chen & Spence, 2017).

Method

PARTICIPANTS

Forty-six students (43 women, M_{age} = 19.67; *SD* = 1.33) from Clermont Auvergne University participated in this experiment in exchange for course credits. All participants were native French speakers and had normal or corrected-to-normal hearing and vision.

This study was approved by the Ethical Committee of the Clermont Auvergne University (IRB00011540-2019-16), and all participants signed informed consent forms before the experimental session started. Each participant was tested individually in one session (≈ 45 minutes).

APPARATUS AND MATERIALS

The experiment was conducted on a Dell Latitude 7490 computer with an integrated 14 in. screen running Windows 10 Pro 64bit and using Opensesame 3.2.8, with a screen resolution of 1980 × 1080 pixels (Mathôt et al., 2012). PyGame was used as a backend to develop, set up, and run the experiment.

Twelve colors and 12 sounds were used to construct high and low overlap conditions (4 colors and 4 sounds in each overlap condition, and 4 other colors and 4 other sounds for the practice trials). There were four visual items per level of overlap (low vs. high), corresponding to the four tiles of the 2 × 2 matrix in the Simon task. Four auditory items corresponded to the four tiles of the 2 × 2 matrix.

For the visual stimuli, the activation of a tile was indicated by increasing the brightness (light on) of this tile compared to the default display. All the visual stimuli had the same format (250 × 250 pix with a resolution of 159 × 159 dpi). The low and high visual overlap stimuli corresponded to red-green-blue (RGB) values. The high overlap stimuli made use of four shades of gray and the low overlap stimuli were displayed in four specific colors (red, blue, green, and yellow). In the auditory variation condition, the visual stimulus was a visual mask used in Vallet et al. (2013). A visual mask was chosen because it consisted of a mixture of shapes and colors. Therefore, it did not resemble any particular color used in the experiment.

For the auditory stimuli, the activation of the tiles was indicated by an acoustic tone. The high overlap stimuli were four tones differing by an 8 Hz gap and the low overlap stimuli took the form of four other tones differing from one another by 125 Hz. In the visual unimodal discrimination condition, the auditory stimulus was white noise. White noise was chosen because it combines the entire audible frequency range. Therefore, it does not resemble any specific tone.
In the audiovisual discrimination condition, the visual stimuli were those of the visual unimodal discrimination condition and the auditory stimuli were those of the auditory unimodal discrimination conditions. Thus, in the audiovisual discrimination condition, both the visual and auditory stimuli were different from each other. The specific characteristics of each stimulus in the activation and standard modes for all experimental conditions are presented in Table 1.

A pretest involving 10 students was conducted to ensure that it was easier to discriminate the stimuli in the low overlap condition than in the high overlap condition and, more importantly, to ensure that this manipulation led to equivalent effects for the visual and auditory stimuli (see the Supplementary Material).

Twenty spatial sequences with a length of 20 items each were generated using an algorithm that ensured that the same item could not be presented twice in a row and that the first four items were different across all the trials. To avoid any spatial effect of a given sequence on performance across the conditions, the same sequences were presented in each condition. However, the order of presentation of the sequences was randomized within each condition. Indeed, although the Simon task did not appear to present any proactive interference between sequences (Gendle & Ransom, 2006), this control prevented learning effects. In addition, the order of presentation of the conditions was counterbalanced in a between-subjects manner.

TABLE 1.
Visual and Auditory Stimuli for Each Condition in Experiment 1A

Condition	Visual stimulus	Standard visual stimuli	Visual activation	Auditory activation
Visual-High	Gray N°1	146, 146, 146	201, 201, 201	White noise
	Gray N°2	164, 164, 164	219, 219, 219	White noise
	Gray N°3	182, 182, 182	237, 237, 237	White noise
	Gray N°4	200, 200, 200	255, 255, 255	White noise
Visual-Low	Green	0, 185, 0	0, 255, 0	White noise
	Blue	0, 0, 185	0, 0, 255	White noise
	Red	185, 0, 0	255, 0, 0	White noise
	Yellow	230, 210, 0	255, 255, 0	White noise
Auditory-High	Visual mask	Low light	High light	338 Hz
	Visual mask	Low light	High light	346 Hz
	Visual mask	Low light	High light	354 Hz
	Visual mask	Low light	High light	362 Hz
Auditory-Low	Visual mask	Low light	High light	175 Hz
	Visual mask	Low light	High light	300 Hz
	Visual mask	Low light	High light	425 Hz
	Visual mask	Low light	High light	550 Hz
Audiovisual-High	Gray N°1	146, 146, 146	201, 201, 201	338 Hz
	Gray N°2	164, 164, 164	219, 219, 219	346 Hz
	Gray N°3	182, 182, 182	237, 237, 237	354 Hz
	Gray N°4	200, 200, 200	255, 255, 255	362 Hz
Audiovisual-Low	Green	0, 185, 0	0, 255, 0	175 Hz
	Blue	0, 0, 185	0, 0, 255	300 Hz
	Red	185, 0, 0	255, 0, 0	425 Hz
	Yellow	230, 210, 0	255, 255, 0	550 Hz

PROCEDURE

The participants were placed in a dark room in front of a computer (≈ 60 cm) with a lamp placed under the table. Each participant started with four practice trials. The colors and sounds used for the practice trials and the presented spatial sequences were different from those used for the experiment. The participants were instructed to reproduce identically as many sequences as possible. After the practice phase, the participants performed the first block of trials consisting of 12 memory spans and corresponding to two measures per condition. Since the entire experiment consisted of two blocks, four memory spans were measured per condition (similar to Gendle & Ransom, 2006). The participants' task was to reproduce spatial sequences. For each memory span, the number of items at the start of the sequence was randomized between four and six.

An algorithm adapted from Pisoni and Cleary (2004) was used to measure the memory span for the spatial sequences (see Figure 1). A memory span in a condition corresponded to the length of the last successfully reproduced sequence when at least one sequence had been correctly reproduced followed by two successive errors on sequences of the same length.

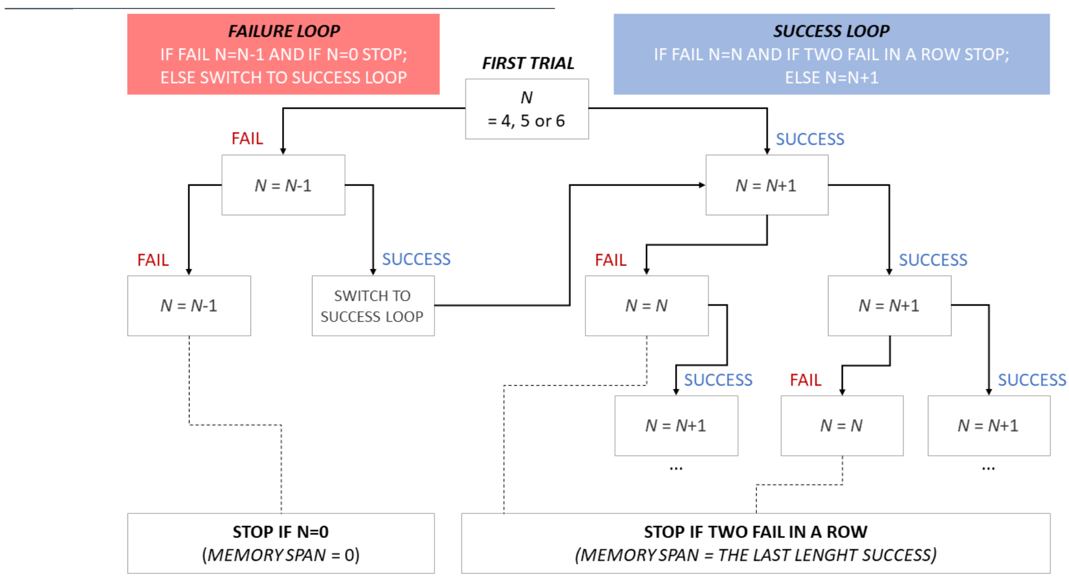

FIGURE 1.

Illustration of the algorithm used to measure the memory span. It consisted of two different loops, a success loop and a failure loop. For instance, if the length of the sequence started at 4 and if the participant correctly reproduced the sequence, then the next sequence had a length of 5 (the participant enters the algorithm's success loop). If the participant failed, then a new sequence of 5 was presented. The algorithm would stop if the participant made another error and the memory span would then be 4 (the last correctly reproduced length), otherwise a new sequence of length 6 would be presented and would increase (N+1) until the participant made two errors in a row. If the participant failed to reproduce the initial sequence, a new sequence of 3 was presented (the participant enters the algorithm's failure loop). This loop was only activated if the participant started the memory task with a failure.

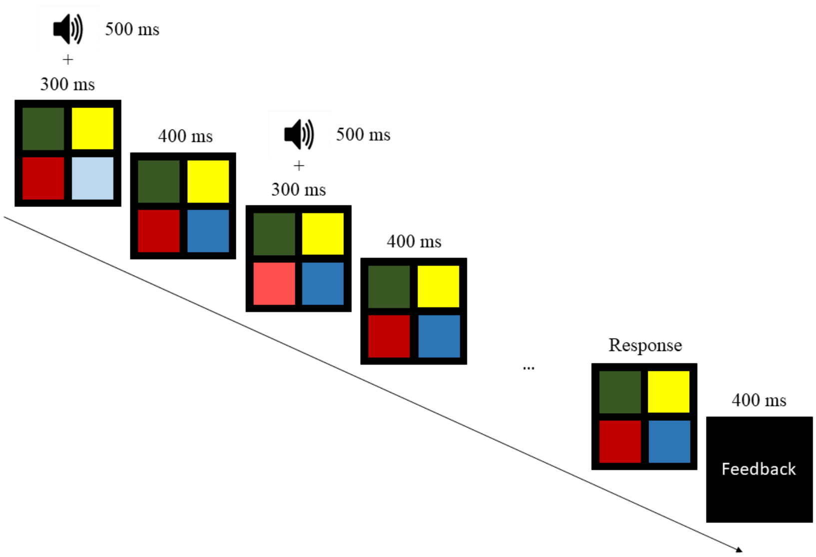

FIGURE 2.

Illustration of a trial in Experiment 1A. In this example, the blue tile in a 2 x 2 matrix was activated for 300 ms, a sound was played for 500 ms, the blue tile was not activated for 400 ms, the red tile was activated for 300 ms, and a sound was played for 500 ms; the red tile was not activated for 400 ms. At the end of the sequence, the participant had to correctly reproduce the sequence by touching the tiles, before feedback was displayed for 400 ms.

The procedure for a trial was as follows (see Figure 2): the 2 × 2 matrix was presented, and a visual tile was then activated for 300 ms while a sound was played for 500 ms. The tones were activated for a longer duration than the visual stimuli due to retinal persistence, which induces a slower decay of visual stimulation compared to auditory stimulation. Another tile was then activated, and so forth, until the entire sequence had been presented. The interval between two activations was set to 400 ms. At the end of the sequence, the participants had to reproduce the sequence correctly by pressing the tiles (on a touch screen) in the right order. Feedback on the correct/incorrect status of the response was then displayed for 400 ms before a new sequence started.

At the end of the block, the participants had a break of 2 to 5 min during which they completed the Plymouth Sensory Imagery Questionnaire (a mental imagery questionnaire, Andrade et al., 2014) as a filler task. The participants then performed a second block, again with 12 memory spans (two per condition).

Results and Discussion

Three participants were excluded because they reported having great difficulty spotting the tiles that became activated. The data were analyzed in R v4.0.4, using *RStudio* software (R Core Team, 2018). The mean memory spans were calculated across participants for each experimental condition. Our hypotheses were examined using Bayes factors ("BayesFactor" package, Morey et al., 2018) with the default prior settings to compute Bayes factors (BFs). The BFs range on a continuous scale from 0 to + ∞, with a BF of 1 reflecting perfect ambiguity (the data support both hypotheses equally). BFs below 1 represent evidence for the hypothesis in the denominator (typically H0), and BFs above 1 indicate evidence in favor of the hypothesis in the numerator (typically H1). The BF values have been interpreted from the recommendations provided by van Doorn et al., (2020). For H1 BFs between [1-3] indicate weak evidence; [3-10] indicate moderate evidence, and strong evidence is indicated if BF > 10. For H0, BFs between [1-1/3] indicate weak evidence; [1/3 - 1/10] indicate moderate evidence, and strong evidence if the BF < 1/10. Overall, the effects should be taken into account at least at a moderate level of evidence. A Bayesian analyses of variance (ANOVA) were performed on the mean memory spans using a 2 × 3 (overlap [low vs. high] × 3 discrimination modality [visual, auditory, audiovisual]) repeated-measures design. The values of the BFs are those of the models corresponding to the comparison of one or more factors relative to the intercept-only model (without the main effects and the interaction terms). To examine our contrast hypothesis more specifically, planned comparisons were performed using a Bayesian paired one-tailed *t*-test.

Out of all possible models involving the main effects of overlap and discrimination modality as well as the two-way interaction, the preferred model was the main effect of overlap. Indeed, aggregated over all models, there was moderate evidence for the main effect of overlap, BF10 = 6.050, with a lower memory span in the high overlap condition than in the low overlap condition; weak support for null evidence for the main effect of discrimination modality, BF10 = .422, and very weak evidence against the interaction, BF10 = .861[2].

Based on our a priori hypotheses, a post-hoc test was conducted to compare the overlap effect for each discrimination modality condition (see Figure 3 and Table 2). The results provided strong support for the overlap effect in the visual condition (BF10 = 34.871), weak evidence in favor of a null effect of overlap in the audiovisual condition (BF10 = .789), and moderate evidence in favor of a null effect of overlap in the auditory condition (BF10 = .230).

As expected, the data showed lower performance in the high overlap condition than in the low overlap condition. The data strongly support that high overlap in the visual discrimination condition led to a lower memory span than the corresponding low overlap condition. In contrast, the analyses provided a weak to moderate evidence for a null effect of overlap in the auditory condition and audiovisual discrimination conditions. This suggests that the visual modality drives the Simon task. Since the task has a spatial component, this could be partly explained by the fact that the emission of the auditory signals was not spatialized, contrary to the visual signals (Chen & Spence, 2017). Another interpretation would come from the modality effect that designates a stronger recency effect (i.e., the benefits for the last items in a sequence) for auditory items relative to visual items, an effect that is also found in spatial memory tasks (Tremblay et al., 2006). The large recency effect in the auditory modality may have facilitated the reconstruction of the last items of the spatial sequence, which, in turn, may have reduced the benefit of a low sensory overlap between the items. Nonetheless, no overlap effect was observed in the audiovisual variation. Since the visual stimuli in the audiovisual condition are the same as those used in the unimodal visual discrimination condition, the lack of effect of visual overlap can only be explained by the addition of specific sounds to the visual tiles. Therefore, the audiovisual condition would have counteracted the detrimental effect of the high visual overlap, possibly due to better discrimination of the memory traces. One may argue that the audiovisual nature of the variation generated a specific pattern that could be more easily learned and reactivated, going beyond the benefit of low visual overlap. More specifically, the unique visual and auditory combination for each tile may have reduced the overlap occurring in unimodal stimulations, so the degree of overlap may have been of lesser benefit.

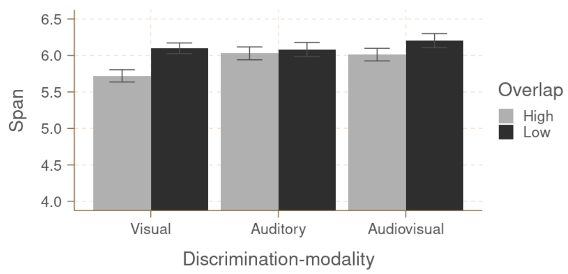

FIGURE 3.

Mean memory span for low and high overlap conditions and discrimination modality (visual, auditory, or audiovisual) in Experiment 1A. Gray bars represent standard errors corrected for the within-participant design.

TABLE 2.
Descriptive Statistics of the Span Memory Task as a Function of the Discrimination-Modality (Visual vs. Auditory vs. Audiovisual) and Overlap (High vs. Low)

		Span	
Discrimination-Modality	Overlap	*M*	*SD*
Visual	Low	6.10	0.78
	High	5.72	0.85
Auditory	Low	6.08	0.81
	High	6.03	0.89
Audiovisual	Low	6.20	1.08
	High	6.01	0.93

These results suggest that the benefit of low overlap is increased when the trace has a high likelihood of suffering from discrimination difficulty, that is, when only a unimodal component is available to discriminate one element for the others. However, another explanation would be that the participants used the specific verbal labels for the colored tiles (Diamantopoulou et al., 2011). In this case, better memory span in the visual low overlap condition may reflect an enrichment of the memory traces by the use of the dual coding (Paivio, 1971, 2007) principle (visual and verbal), while the shades of gray would only have unimodal coding (visual). If this is true, then blocking verbal recoding should eliminate the effect of visual overlap, as was tested in Experiment 1B.

EXPERIMENT 1B

This experiment tested whether the visual overlap effect could be replicated under an articulatory suppression condition. The hypothesis was that if the visual overlap effect is driven by verbal recoding (Diamantopoulou et al., 2011), then articulatory suppression performed during the task should cancel out the effect. On the other hand, if the visual overlap effect is not produced by verbal recoding, then the addition of this instruction should not impact the effect observed in Experiment 1A. Since this hypothesis focused on the distinction between the color and gray conditions, the other conditions were excluded from this experiment. Two levels of overlap (low vs. high) of visual stimulation were then tested in a condition of articulatory suppression.

Method

PARTICIPANTS

Thirty students (28 women, M_{age} = 19.52; *SD* = 1.11) completed the experiment with the same criteria as Experiment 1A. This study was approved by the Ethical Committee of the Clermont Auvergne University (IRB00011540-2019-16), and all participants signed informed consent forms before the experimental session started. None of them took part in Experiment 1a. Each participant was tested individually (≈ 15 minutes).

APPARATUS AND MATERIALS

Two conditions were presented: low and high visual overlap. These conditions did not include any sound and were performed under articulatory suppression. The white noise was removed to avoid disrupting the rehearsal suppression rhythm. The articulatory suppression was supposed to prevent the verbal rehearsal of the heard stimuli (Baddeley, 1990). The participants were instructed to repeat the syllable \ba\ every 500 ms, that is, a frequency that corresponded to the rhythm of tile activation. It should be noted that the participants were instructed to continue the articulatory rehearsal even when they were reproducing the sequence. The visual stimuli were identical to those described in Experiment 1A.

Four blocks of 20 spatial sequences with a length of 20 items each were generated using the same algorithm as in Experiment 1A. Each of these four blocks included a low and high visual overlap condition. The same sequences were presented in each condition in each block. However, the order of sequence presentation was randomized for each condition. In addition, the order of presentation of the conditions was randomized.

PROCEDURE

The procedure of this experiment was similar to that of Experiment 1A, except that the participants completed only two experimental conditions in one block: low and high visual overlap. No sound was presented in Experiment 1B, and the participants always performed the task under the condition of articulatory suppression.

Results and Discussion

Two participants were excluded because they reported having great difficulty spotting tiles that became activated. The data were analyzed using the same procedure as that used in Experiment 1A. The difference between the low and high visual overlap conditions was assessed by a Bayesian paired one-tailed *t*-test.

The analyses showed moderate support for the overlap effect (BF10 = 5.586) with a lower memory span in the high overlap condition (*M* = 5.21, *SD* = 0.83) than in the low overlap condition (*M* = 5.50, *SD* = 0.76).

The data showed that the visual overlap effect in Experiment 1A cannot be explained simply through the use of a verbal strategy (see also Guitard & Cowan, 2020), as an overlapping effect was observed under articulatory suppression, which prevented verbal recoding of the color of the stimuli. This confirms that the benefit of a low visual overlap occurs in the Simon task, possibly especially for the unimodal discrimination (cf. Experiment 1A). In other words, whereas in the unimodal discrimination condition, the visual low overlap condition led to better span performance than the high overlap condition, this difference seemed to be reduced when the discrimination was audiovisual (when a different sound was associated with the visual tiles). Discrimination of the memory traces could be facilitated for audiovisual traces, as a conjunction of characteristics and sensory modalities strongly reduces overlap and allows the cognitive system to find specific combinations between similar mnemonic traces (Ekstrom & Yonelinas, 2020; Kent et al., 2016). This is consistent with our hypothesis that unimodal discrimination would be less beneficial for the specificity of the memory trace than multimodal discrimination, because the presence of more features makes each trace more specific. As such, one possibility is that the addition of one modality enriches the memory trace at encoding, thus increasing the subsequent discrimination of the traces during the test. Indeed, the letter-color binding allowed, for instance, to reduce the detrimental effect of visual similarity (Morey et al., 2018). Therefore, it would be the richness (here, the number of dimensions) of the trace (Ekstrom & Yonelinas, 2020) rather than the multimodal nature of the stimuli that would strongly facilitate the discrimination between the traces. If so, then the use of more complex visual stimuli should reduce the benefit of unimodal discrimination by adding more richness to the memory trace, as was tested in Experiment 2.

EXPERIMENT 2

Experiment 1A suggested that the Simon task relies more on the visual than the auditory modality. Thus, in Experiment 2, we did not include a unimodal auditory condition, and a unique level of audiovisual discrimination was used. This experiment aimed to replicate the visual overlap effect as a function of the number of discrimination components to determine whether it is the richness of the stimuli (more dimensions) that drives memory specificity (Ekstrom & Yonelinas, 2020; Kent et al., 2016) or whether multimodal discrimination is required to generate the most specific knowledge. To this end, simple visual stimuli used in Experiments 1A and 1B (colored tiles) have been replaced by more complex, meaningful photographs. This choice reduced the overlap in memory by adding a large number of visual components (shape, size, etc.) that should increase physical discrimination (Ensor et al., 2019; Mintzer & Snodgrass, 1999). If multimodal discrimination is necessary to increase the specificity of memory traces, then manipulation of the intrinsic overlap of the rich stimuli (low vs. high) should replicate the results of Experiment 1A, that is, a detrimental effect of the intrinsic visual overlap of the stimuli (low < high) for memory performance, especially for the unimodal discrimination condition. Indeed, based on the results of Experiment 1A, multimodality should not increase performance beyond the benefit of low overlap in the unimodal discrimination condition. On the other hand, if the richness of the stimuli is sufficient to increase the specificity of memory traces (beyond multimodality), then no difference should be observed between the low and high visual unimodal discrimination conditions. Intrinsic visual discrimination of the stimuli should be ineffective when richer visual stimuli are used. To generate a visual overlap effect, it would then be necessary to increase the overlap of the traces by an additional extrinsic manipulation (blurred vision) of the visual overlap. A perceptual degradation should be directly associated with more overlap encoding and, therefore, also with greater difficulties during retrieval (Mille et al., 2021; Surprenant et al., 2006), allowing overlap to bring a significant benefit to the task.

The intrinsic visual overlap was manipulated through the color of the photographs (colors vs. black-and-white). Extrinsic visual overlap was achieved using a lens that caused blurred vision (visual degradation vs. no visual degradation). The photographs of significant, meaningful concepts may induce physical (Mintzer & Snodgrass, 1999) as well as conceptual distinctiveness facilitating the discrimination of traces (Hamilton & Geraci, 2006). As the use of blur-inducing glasses could interfere with the identification of the concepts represented in the photographs, a visual degradation effect would be difficult to interpret. It could be the result of the increased visual overlap of the traces or the lack of meaning of the photographs induced by the visual degradation. To distinguish between these two possibilities, we added a congruent sound condition that allowed access through a sound to the concept (i.e., the meaning) that was represented in the photographs. This condition ensured that the participants could access the concept of the photographs even if the visual degradation did not allow this access from the visual modality. In other words, this condition enabled us to examine whether visual degradation eliminates conceptual distinctiveness. If this is the case, then memory performance in a visual degradation condition without sound should be lower than in a congruent sound condition that compensates for the reduction in visual input by allowing the activation of the concept (see the principle of inverse effectiveness, Stein & Meredith, 1993). Moreover, to differentiate audiovisual discrimination from compensation for visual degradation by the use of congruent sound, the audiovisual discrimination condition with tonal sound was maintained. As such, there were three audiovisual discrimination conditions: none, tones, and congruent (i.e., the typical sound associated with stimuli).

In the unimodal discrimination condition, the 2 × 2 matrix consisted simply of four photographs whereas in the audiovisual discrimination condition, four photographs and four auditory stimuli were used: photographs and piano chords for the tone-audiovisual condition and photographs and semantically congruent sounds for the congruent-audiovisual condition. These conditions were crossed with the extrinsic visual overlap factor (degradation vs. no degradation), leading to twelve conditions.

Since audiovisual discrimination should reduce the overlap between memory traces, it was predicted that memory performance would not be affected by the level of visual overlap in the audiovisual discrimination condition at both intrinsic and extrinsic levels. Conversely, since unimodal discrimination is likely to overlap, memory span should be reduced in the low visual overlap condition in the unimodal discrimination condition. More precisely, because the photographs are richer visual stimuli than those used in Experiment 1, intrinsic visual overlap alone should not reduce memory span. However, the extrinsic visual overlap was expected to reduce memory span only in the intrinsic low visual overlap, but not in the intrinsic high visual overlap condition.

Method

PARTICIPANTS

Thirty students (20 women, M_{age} = 19.83; *SD* = 1.26) completed the experiment with the same criteria used in Experiments 1A and 1B. This study was approved by the Ethical Committee of the Clermont Auvergne University (IRB00011540-2019-16), and all participants signed informed consent forms before the experimental session started. None of them took part in Experiments 1A or 1B. Each participant was tested individually (≈ 45 minutes).

APPARATUS AND MATERIALS

In the extrinsic visual overlap condition, the participants' vision was either degraded (high overlap condition) or not (low overlap condition). The visual degradation was produced by glasses that blurred the participants' vision (DriveCase –C6011-3, cataract simulation 6/120). In half of the trials, the participants wore lenses that induced visual blurring (no blurring in the other half). The participants could wear their own glasses underneath the lenses (when necessary). In trials in which no blurring was induced, the participants wore the glasses without the lenses that induced the blur. In the case of intrinsic visual overlap, the low overlap condition consisted of color photographs, while the high overlap condition consisted of the same photographs converted to black-and-white to increase the overlap (Ensor et al., 2019). There were three audiovisual discrimination conditions: none, corresponding to a unimodal discrimination; tones, corresponding to an audiovisual discrimination tone stimulation with four piano chords (C, D, E, and F); and congruent, corresponding to an audiovisual discrimination semantically congruent stimulation with the typical sound associated with the content of the photographs (e.g., barking sound for a photograph of a dog).

PROCEDURE

Each participant started with two blocks of practice trials with feedback to indicate correct/incorrect responses. The first block was performed without and the second with the blur-inducing glasses. The practice trials with and without the blur-inducing glasses ended after three correct trials in each visual condition. The photographs and semantic sounds used for the practice trials and spatial sequences were different from those used for the experimental phases. As in Experiments 1A and 1B, the participants' task was to reproduce spatial sequences. For each memory span, the number of items at the start of the sequence was randomized between 2 and 4.

After the practice phase, the participants performed a first block of 12 memory span sequences, corresponding to one measure per condition. Since the entire experiment consisted of two blocks, two memory spans were measured for each condition. The participants began with six memory span sequences with or without visual blurring. The order of the tests with or without visual blurring was counterbalanced between participants.

The same memory span algorithm used in Experiments 1A and 1B was used. The procedure for a trial was as follows (see Figure 4): a fixation dot (750 ms) and then the 2 × 2 matrix was presented, and a tile was activated. To make it less difficult for the participants to locate the activated tile when wearing blur-inducing glasses, the tile was no longer activated by illuminating the content but instead by increasing the size of the picture to 398 × 398 px. It was difficult to manipulate the brightness of the photographs containing multiple colors and the blur induced by the glasses made the illumination ineffective. Each matrix consisted of two animals and two artifacts photographs. Each condition used different stimuli. The association between conditions and stimuli was counterbalanced between the subjects. The same stimuli were used in the visual degradation versus no visual degradation conditions. Activation of the tile was indicated by increasing the size of the photograph for 500 ms and by playing a sound for 1 s. Another tile was then activated, and so forth, until the end of the sequence. The interval between two activations was set at 500 ms. At the end of the sequence, the participants had to reproduce the sequence correctly by pressing

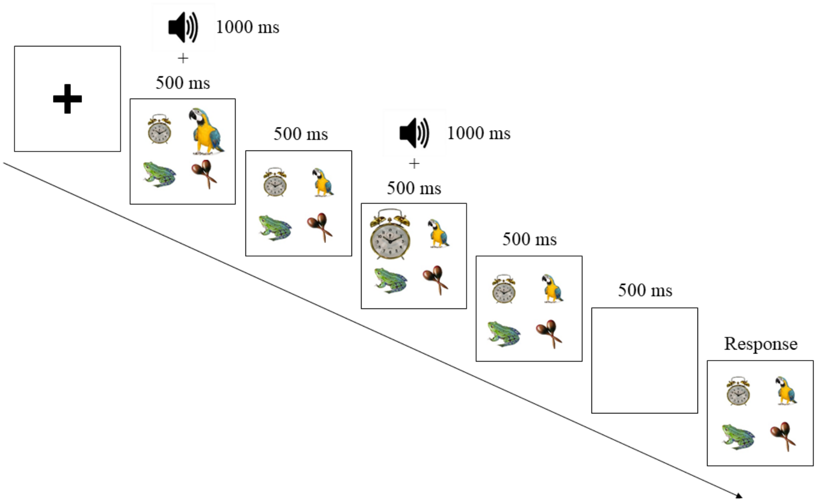

FIGURE 4.

Illustration of a trial in Experiment 2. In this example, a fixation point is presented for 750 ms, the parrot tile in a 2 × 2 matrix is activated for 500 ms, a sound is played for 1 s, the parrot tile in not activated for 500 ms, the alarm clock tile is activated for 500 ms, a sound is played for 1 s, the alarm clock tile is then not activated for 500 ms. At the end of the sequence, the participants had to correctly reproduce the sequence by touching the tiles.

the tiles (on a touch screen) in the right order. The interval between two sequences was set at 500 ms.

Results and Discussion

The data were analyzed using the same procedure as in Experiments 1A and 1B. Bayesian ANOVAs were performed on the mean memory spans. The analyses were performed according to a 2 × 2 × 3 (extrinsic visual overlap [visual degradation vs. no visual degradation] × intrinsic visual overlap [low vs. high] × audiovisual discrimination [none, tone, or semantic]) repeated-measures design, and contrast hypotheses were examined by planned comparison tests using Bayesian paired one-tailed *t*-tests.

Out of all possible models involving the main effects of extrinsic visual overlap, intrinsic visual overlap, and audiovisual discrimination as well as the two-way and the three-way interaction, the preferred model included the main effect of extrinsic visual overlap. Indeed, aggregated over all models, there was weak evidence for the main effect of overlap, BF10 = 1.934, with a lower memory span in the visual degradation condition than in the no visual degradation condition, moderate support for null evidence for the main effect of intrinsic visual overlap, BF10 = .147, strong evidence against the two-way interaction between extrinsic visual overlap and intrinsic visual overlap, BF10 = .047, strong support for null evidence for the main effect of audiovisual discrimination, BF10 = .095, strong evidence against the two-way interaction between extrinsic visual overlap and audiovisual discrimination, BF10 = .015, strong evidence against the two-way interaction between intrinsic visual overlap and audiovisual discrimination, BF10 = .001, and strong evidence against the three-way interaction between extrinsic visual overlap, intrinsic visual overlap, and audiovisual discrimination, BF10 < .001. Based on our a priori hypotheses, post-hoc tests were conducted (see Figure 5 and Table 3), indicating moderate support for a null effect of intrinsic visual overlap (BF10 = .168). This null effect of intrinsic visual overlap was also found in the none audiovisual discrimination condition with moderate support (BF10 = .403). Regarding the extrinsic visual overlap, in the none audiovisual discrimination condition, the results provided moderate support for the low intrinsic visual overlap effect (BF10 = 6.155), and weak support for the high intrinsic visual overlap effect (BF10 = 1.553). In the tone-audiovisual discrimination, the results provided weak support in favor of a null effect of both low intrinsic visual overlap (BF10 = .521) and high intrinsic visual overlap (BF10 = .382). The data also weakly support a null effect in the semantic-audiovisual discrimination condition in both low intrinsic visual overlap (BF10 = .268) and high intrinsic visual overlap conditions (BF10 = .590). Finally, in the visual degradation condition, the results provided moderate support for a lack of difference between the none and semantic-audiovisual discrimination conditions (BF10 = .123), and the same moderate support for a lack of difference between these two conditions was also found for visual degradation in the low intrinsic overlap condition (BF10 = .278).

The results suggest lower memory performance when visual overlapping was at its highest, but especially when the discrimination of the traces was unimodal. Only the most overlapping condition (intrinsic low unimodal discrimination condition) showed conclusive evidence

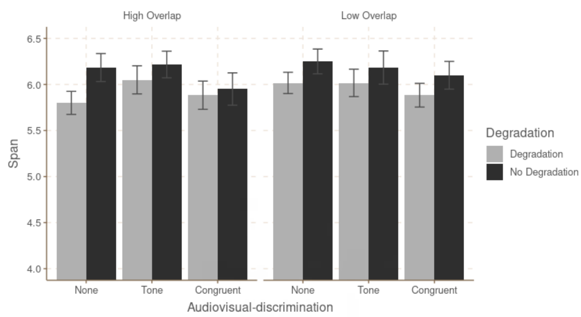

FIGURE 5.

Mean memory span for extrinsic visual overlap using blur induction (visual degradation vs. no visual degradation), intrinsic visual overlap (high vs. low), and audiovisual discrimination (none, tone-audiovisual, or congruent-audiovisual) conditions in Experiment 2. Gray bars represent standard errors corrected for the within-participant design.

(here moderated) for the effect of extrinsic overlap. The other conditions provided weak or moderate support of a lack of difference for this factor (or were inconclusive, with a BF very close to 1). Extrinsic visual overlap occurred mainly in the case of unimodal discrimination and was at its greatest for intrinsic high visual overlap. This effect was not due to an inability to spot the activation of tiles as none of the participants reported having difficulty performing the task, which simply required them to identify a change in picture size. Therefore, visual details were not relevant. Moreover, the results cannot be explained by the fact that visual degradation would have eliminated better discrimination of traces induced by conceptual distinctiveness (Hamilton & Geraci, 2006), because the congruent sound had not compensated for the visual degradation (Stein & Meredith, 1993) and the congruent-audiovisual discrimination condition had not increased performance (including for the intrinsic low visual overlap condition). Therefore, the overlap of the memory traces in the Simon task would be more induced by a reduction in the richness of stimuli (Ekstrom & Yonelinas, 2020; Kent et al., 2016) than by audiovisual discrimination per se. Therefore, the greater benefit of a low visual overlap in the unimodal discrimination condition than in the audiovisual discrimination condition may come from encoding richer stimuli rather than from adding a sensory modality. Audiovisual discrimination would be beneficial when the stimuli are basic and poor (few dimensions, as in Experiment 1A), but not when they are enriched by many features (as in Experiment 2). This suggests that the multimodal discrimination is similar to an enrichment of the memory traces.

Memory span performance was lower when the visual overlap was at its highest (visual degradation with black-and-white photographs stimuli), but especially in the unimodal-discrimination condition. These results are particularly interesting because the task did not require any recall of the sensory stimuli themselves. The participants were only asked to reproduce the visuospatial sequences, meaning that the content of the tiles was not central to the task requirements. Despite this, performance was be lower when the overlap was at its highest, that

TABLE 4.

Descriptive Statistics for the Span Memory Task as a Function of the Audiovisual-Discrimination (None vs. Tone vs. Congruent), Intrinsic-Overlap (High vs. Low) and Extrinsic-Overlap (Visual Degradation vs. No Visual Degradation)

			Span	
Audiovisual-Discrimination	Intrinsic-Overlap	Extrinsic-Overlap	*M*	*SD*
None	Low	Degradation	6.02	0.97
		No degradation	6.25	1.09
	High	Degradation	5.80	0.99
		No degradation	6.18	0.99
Tone	Low	Degradation	6.02	1.09
		No degradation	6.25	1.08
	High	Degradation	6.05	1.07
		No degradation	6.22	0.85
Congruent	Low	Degradation	5.88	0.85
		No degradation	6.10	1.23
	High	Degradation	5.88	1.02
		No degradation	5.95	1.24

is, when the sensory trace was unimodal and the visual tiles were the poorest (grey tiles in Experiments 1A and 1B, visual degradation and black-and-white photographs in Experiment 2).

GENERAL DISCUSSION

The current study aimed at identifying when and how high overlap between memory traces is detrimental to memory specificity. More precisely, as the reduction of the sensory overlap was thought to be mainly useful when the cognitive system fails to discriminate memory traces, the experiments explored when increased sensory overlap decreases specific memory. Two experiments examined the interplay between the level of sensory overlap (low vs. high) and the number of discrimination components (unimodal vs. multimodal). As predicted by the Act-In model (Versace et al., 2009, 2014), memory span was lower when the visual overlap was at its highest (high likelihood that activation diffuses to the other traces), especially when the memory discrimination was unimodal. The visual overlap effect was also found when the participants performed articulatory suppression (Experiment 1B), suggesting a visual nature effect. Moreover, the richer visual dimensions (shape, size, etc.) of the photographs used in Experiment 2 appeared to limit the diffusion of the activation to other memory traces, as the visual overlap effect mainly occurred revealed in the extrinsic degradation condition. Therefore, the reduced overlap in the reconstruction of spatial sequences seems more impacted by a dimensional discrimination (Ekstrom & Yonelinas, 2020; Kent et al., 2016) than by multimodal discrimination per se. Taken together, the results of the current study are consistent with the hypothesis that the overlap is mainly detrimental when at its highest (Ekstrom & Yonelinas, 2020; see also Saksida & Bussey, 2010, for a similar proposition in a neurophysiological model), and seem to be particularly well explained by the Act-In model.

Specific knowledge, such as a trial in the Simon task, should emerge when the activation from the current situation propagates to each component of the memory trace (intratrace activation in Act-In), and when this propagation across the other memory traces (intertrace activation) remains limited. It is worth mentioning that each form of activation inhibits the other. Intratrace activation is facilitated by the specificity of the trace, greatly determined by the overlap of one or more components (richness and/or multimodal discrimination). Intratrace activation is enabled by the multi component integration of the various stimuli of an event. It is likely that the simultaneous presentation of the visual stimuli in a matrix form favored the integration (binding) of the stimuli with the location (see Guérard et al., 2009). As in other multiple-traces memory models, the final activation of one specific memory occurs when the intracomponent discrimination is facilitated due to low overlap between traces (Hintzman, 1986). In the current study, the participants had to reproduce the spatial sequences produced by the successive activation of the four tiles. Since the tiles were very similar (especially in Experiments 1A and 1B) and since a same tile could be activated several times in a same trial, the intertrace activation was greatly reinforced (and thus intratrace activation was reduced). The tiles presented in shades of gray (Experiments 1A and 1B) or as black-and-white photographs, especially in combination with extrinsic sensory degradation (Experiment 2), would have further increased intertrace activation and thus the likelihood of overlapping. Conversely, color tiles (Experiment 1) or color photographs, especially with no extrinsic visual degradation (Experiment 2), would thus facilitate intratrace activation and to reduce the likelihood of overlapping (reduce intertrace activation). Such low sensory overlap was able to increase memory performance mainly in the unimodal conditions because the discrimination of multimodal traces is more effective than that of unimodal traces. The presence of a larger number of modalities greatly decreases the likelihood of overlapping between similar traces (more efficiently reduces intertrace activation), which hinders the emergence of specific knowledge (accurate reconstruction). Another nonmutually exclusive interpretation of the increased benefit of multimodal traces for specificity would be that the integration of multiple modalities within the trace could also result in a less overlap representation due to an emergent principle that "the whole is greater than the sum of the parts" (Kent et al., 2016, p. 101). Nonetheless, the intertrace activation is generally beneficial for the cognitive system, as it is thought to underpin categorical knowledge (e.g., semantic knowledge, Versace et al., 2014).

This interpretation also reflects other models. For instance, the Scale-Invariant Memory, Perception and Learning (SIMPLE) model (Brown et al., 2007) proposed a computational local distinctiveness account along one or several dimensions. Memory is defined in terms of discrimination. Items are represented in positions along one or more dimensions, and items with close neighbors on the relevant dimensions at the time of retrieval are less likely to be recalled than distant neighbors. The results of the current study are consistent with the predictions of the SIMPLE model since overlapping is mainly critical when it is at its highest. As such, and as in the SIMPLE model, the manipulation of the overlap in our experiments was relative and must be understood through the notion of overlapping features between memories.

Nevertheless, one might argue that the results in these studies come from attention-based mechanisms rather than memory ones. For instance, it is conceivable that low visual overlap could be visually more salient than high visual overlap. However, this hypothesis would either predict that this salience effect should also occur in a multimodal discrimination condition, which is not consistent with the results of Experiments 1A and 2, or that multimodal stimulation leads to resource sharing (Santangelo et al., 2010) and cancels out the beneficial effect reported in the low overlap conditions. This second prediction is not in agreement with the results of Experiment 1A, in which all the items were audiovisual, but where the sensory overlap effect occurred, especially in the unimodal discrimination condition. In contrast, in this experiment, attention may have been facilitated by the specificity of the sounds in the audiovisual condition. It could be hypothesized that the change in brightness of the gray stimuli was more difficult to detect than the change in brightness in all other conditions. In the audiovisual condition, attention would have been drawn to the correct tile by the tone sound because of the association between the tile and the tone.

One strength of the current study is that it reports consistent visual overlap effects, especially in the case of unimodal discrimination, based on two experiments using different visual material in the Simon task, a task that does not require focus on overlap or the number of discrimination components. Another strength of the current study lies in the fact that it is one of the few to report a sensory degradation effect in a memory task in young adults (see Monge & Madden, 2016). The results of Experiment 2 suggest that sensory degradation produces an impairment of memory mainly when the material is extremely similar (high overlap) and when the memory task requires very accurate recall (access to specific knowledge).

The hypothesis that sensory degradation impairs specific memory performance mainly when the items have a high level of sensory overlapping is particularly relevant for normal aging, as the sensory decline of older adults may reduce the specificity of their memory traces (e.g., Korkki et al., 2020; see also Mille et al., 2021, for a review). The present study is exploratory and should be replicated. Nonetheless, the experimental manipulation of sensory degradation undertaken in young adults in Experiment 2, which seems to produce harmful effects on memory performance in the most overlapping conditions, could contribute to our understanding of the associations between sensory and cognitive measures in aging (see Roberts & Allen, 2016).

FOOTNOTES

[1] The mechanisms of discrimination are supposed to occur in both short- and long-term memory (see Neath et al., 2014), especially in unitary memory models such as Act-In (see also the SIMPLE model; Brown et al., 2007, for a similar proposition in a computational model).

[2] The values reported for the interaction effects are the sum of the main effects plus the interaction effect. For instance, in this case, the reported value refers to the model which includeds to the sum of the main effect of the overlap, the main effect of the discrimination-modality effect, and the interaction of these two factors.

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All subjects gave written informed consent in accordance with the Declaration of Helsinki. This research was approved by the Ethical Committee of the Clermont Auvergne University (IRB00011540-2019-16 for Experiment 1a and 1b, and IRB0001154062020-07 for Experiment 2).

DATA AVAILABILITY

The data and statistical analysis scripts for all experiments are available at https://osf.io/c7fw5/files/

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SUPPLEMENTARY MATERIALS

Pretest of Experiment 1A Stimuli

In the pretest of Experiment 1A stimuli, the participants had to decide whether two stimuli (auditory or visual) presented one after the other were the same or not. Better discrimination performance occurred in the low visual-overlap (M = 96.25%, SD = 4.37%) than in the high visual-overlap condition (M = 62.08%, SD = 17.36), $t(9)$ = 7.45, p < .001, d = 2.36. The same pattern was revealed for the auditory stimuli, with better discrimination being observed in the low-overlap (M = 94.58%, SD = 5.91%) than in the high-overlap condition (M = 57.08%, SD = 27.32), $t(9)$ = 5.07, p <. 001, d = 1.60. No statistically significant difference was observed between the auditory and visual conditions for either low $t(9)$ = .80, p > .1, or high-overlap, $t(9)$ = .75, p > .1.