



Memory as a scale of simulation depending on the trace distinctiveness

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Abstract

It has been proposed that representations emerge from a single memory system organized along a continuum of specificity. This continuum is assumed to reflect a scale between the simulation of overlapping and specific features of the traces, which depends on trace distinctiveness. More specifically, higher trace distinctiveness facilitates the simulation of trace-specific features, which increase the discriminability of traces and lead to the emergence of a more specific representation. In two experiments, participants were asked to identify match (low task discrimination demand) or mismatch (high task discrimination demand) associations between actions and characters that were visually either highly or lowly distinctive. The results of Experiment 1 show that in the high-distinctiveness context, performance was better when identifying a mismatch rather than a match, while the opposite was true in the low-distinctiveness context. The results of Experiment 2 show that using a dynamic visual noise to interfere with the participants' ability to simulate the features of the characters also reduced the benefit of the high-distinctiveness context for the mismatch trials (Experiment 2a and 2b) and increased the benefit of the low-distinctiveness context for the match trials (Experiment 2b). Taken together, these results suggest that the simulation of trace-specific features underlies the emergence of specific representations, which can be beneficial when the discrimination demand of the task is high and detrimental when this demand is low. Memory might therefore be viewed as a scale of simulation between overlapping and specific trace features.

Keywords Memory · Specificity · Sensorimotor simulation · Discrimination · Trace distinctiveness

Introduction

Memory is increasingly seen as a dynamic system (e.g., Schacter & Addis, 2007a, 2007b; Surprenant & Neath, 2009; Versace et al., 2009; Versace et al., 2014) that does not faithfully retrieve information but rather flexibly reconstructs it (i.e., emerging representations). This flexible reconstruction

allows us to produce a variety of behaviors adapted to the current situation (Schacter, 2012), such as imagining a future scenario (Schacter et al., 2017) or being creative (Addis et al., 2016). However, this flexibility has a cost that results in memory errors. These errors are particularly frequent in the case of overlapping events in which specific components can easily be confused (Belli & Loftus, 1996; Loftus & Palmer, 1974, 1996; Schacter, 2001). Memory efficiency should therefore be characterized not only by the number of items retrieved, but also by the accuracy of recall (see Koriat et al., 2000).

In a multitrace conception of memory, the system accumulates traces, all of which reflect the sensorimotor brain state that occurred while experiencing an event (for instance, see Versace et al., 2009; Versace et al., 2014). In such a conception of memory, representations are not retrieved intact from a store, but emerge here and now from a global matching process between the current situation (its sensorimotor features) and the memory traces (see Hintzman, 1984, 1986). This emergence is often assimilated to a simulation,

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which corresponds to an automatic and mandatory reenactment of the activities in the modal and heteromodal areas of the brain produced by the sensorimotor features of past experiences (Barsalou, 2003, 2008; Barsalou et al., 2003). As different events can share similar sensorimotor features, memory traces can overlap. If the current situation matches many overlapping memory traces, then their overlapping features (perceptually present or not) will be simulated as if they were actually perceived. If the current situation matches a specific memory trace, the specific features of this memory trace will also be simulated. Thus, identifying an object as a hammer can be achieved after simulating the overlapping features of all the memory traces of the events in which we were confronted with a similar object. The simulation of the overlapping features will lead to the emergence of a nonspecific (or abstract) representation of a hammer. While identifying a murder weapon, can only be achieved after simulating the specific features of the memory trace of the event where we were confronted with this particular hammer and by emerging the specific representation of this hammer.

Thus, recalling a specific event can be defined as a task involving the discrimination of a single memory trace among others (Brown et al., 2007; Neath & Brown, 2006; Surprenant & Neath, 2009). On a theoretical standpoint, trace discriminability (i.e., how discriminable the traces are from each other) depends on trace distinctiveness, and what determines trace distinctiveness is the extent to which a trace overlaps other traces from which it has to be distinguished (Hunt, 2013; Hunt et al., 2006; Surprenant & Neath, 2009). Distinctiveness is therefore relative, as a given memory trace must always be contrasted with other traces from which it must be discriminated (i.e., the competing traces). Less distinct traces decrease trace discriminability by favoring the simulation of overlapping features of the traces and thus reducing the specificity of the emerging representation (e.g., Ensor et al., 2019; Guérard et al., 2010). Conversely, more distinct traces are more likely to possess specific features that discriminate them from other traces and increase the specificity of the emerging representation. This relationship suggests the idea of a continuum of specificity of the emerging representation.

The idea that emerging representations are organized along a continuum of specificity is gaining ground. The differences between semantic representations (e.g., general knowledge or facts about the world) and episodic representations (e.g., memory of a unique event) might be better explained in a single system approach through a continuum of specificity. This continuum of specificity can be viewed as going from the least specific emerging representation (as a semantic representation) to the most specific emerging representation (as an episodic representation; see Craik, 2002; Hintzman, 1984, 1986; Keresztes et al., 2018; Versace et al., 2009; Versace et al., 2014), rather than in terms of multiple separate systems (semantic and episodic; see Tulving, 1983, 1984, 1995). This

later conception has been questioned for almost 30 years (see Renoult et al., 2019). The degree of specificity of the emerging representation (i.e., the point on the continuum from which the representation emerges) would depend on the number of traces involved in its emergence, and this would be influenced by trace distinctiveness (i.e., the extent to which the trace has specific features and does not overlap with other traces). As such, the emergence of a nonspecific representation requires a match between the current situation and a large number of overlapping traces. Therefore, nonspecific representation does not require to discriminate between individual traces (see Versace et al., 2009; Versace et al., 2014). By contrast, the emergence of a specific representation requires a match between the current situation and a specific memory trace and makes it necessary to discriminate between specific individual traces. The continuum of specificity can thus be thought of as a scale whose equilibrium depends on the outcome of the simulation. One side corresponds to the emergence of the less-specific representations (e.g., semantic) from the simulation of the overlapping features of the traces. The other side corresponds to the emergence of the most specific representations (e.g., episodic) from the simulation of the specific features of a memory trace. The greater trace distinctiveness is, the more biased the scale will be towards the simulation of specific features (involving few traces) to the detriment of the overlapping features of the traces (involving many traces), and the more specific the emerging representation will be, and vice versa.

Nonetheless, the scale bias would be beneficial or detrimental depending on the discrimination demand of the task (Brunel et al., 2010a; Leritz et al., 2006; Oker & Versace, 2014). Indeed, a task that requires the emergence of nonspecific representations (categorical representation) requires the simulation of the overlapping features of the traces, not the specific ones (Kumaran & McClelland, 2012; McClelland et al., 1995). This type of task does not depend upon participants' ability to discriminate between individual traces, and therefore has a low discrimination demand. Reversely, a task that requires the emergence of specific memories should involve the simulation of the specific features of a single trace, not the overlapping ones (Surprenant & Neath, 2009). This type of tasks implies that participants are able to discriminate between individual traces, and therefore has a high discrimination demand.

Thus, high distinctiveness would create a bias towards the simulation of specific features and would be detrimental for tasks that require the emergence of nonspecific representations (which is the abstraction or synthesis of several single event representations) and beneficial for tasks that require the emergence of the representation of a single event (see Brunel et al., 2013). Conversely, low distinctiveness would create a bias towards the simulation of overlapping features and would be beneficial for tasks that require the emergence of nonspecific representations and detrimental for tasks that require the emergence of a single event. In this latter type of task, the simulation

of the overlapping features of traces increases the likelihood that participants will produce memory errors due to confusions between trace features (Koutstaal et al., 1999; Migo et al., 2013; Purkart et al., 2021; Surprenant et al., 2006). Consequently, two tasks that involve different degrees of specificity of the emerging representation involve different discrimination demands. This distinction is often found between semantic tasks and episodic tasks (the two extremes of the continuum). However, a single-system conception also predicts that the discrimination demand of a given task (e.g., an episodic task) can vary within the same task. If this is true, then, according to the continuum hypothesis, the specificity of the required representation will also vary within the task. The aim of the present study was thus to examine the hypothesis of a continuum of specificity of the emerging representation by testing an interaction between trace distinctiveness and the discrimination demand of a single task that required the emergence of specific memories.

The present study

To examine the hypothesis of a continuum of specificity of the emerging representation, we tested in Experiment 1 if the trace distinctiveness differently impacts performance in a single task that requires the emergence of specific memories but implies a varying discrimination demand. To this end, we used an associative recognition task in which trace distinctiveness was manipulated (Purkart et al., 2021) as well as the discrimination demand of the different trial types. In a study phase, the participants see videos of characters each performing an action (e.g., *sitting on*) on a specific object (e.g., *a chair*) and simultaneously hear an audio track stating the action/object association (e.g., “*sitting on . . . a chair*”). They are asked to memorize the association between the characters and the specific action/object they performed. In each trial of the subsequent recognition phase, they hear an audio track as a cue before a character is briefly displayed. Listening to the audio track cue triggers a simulation of the features of the character associated with the cued action/object. For half of the trials, the character displayed performed the cued action/object in the study phase (MATCH trials), and for the other half, the character performed the same action (e.g., *sit on*) but on a different object (e.g., *a stool*) (MISMATCH trials). The participants are asked to indicate whether the displayed character was identical to the character who performed the cued action/object initially.

According to the principle of encoding specificity (Tulving & Thomson, 1973), the success of retrieval depends on the match between the encoding conditions and the retrieval conditions of the information (see also the Encoding-Recovery principle of Surprenant & Neath, 2009). Therefore, the probability of a successful retrieval increases as the number of overlapping features between the encoding and retrieval conditions increases.

For the MATCH trials, the audio track cue triggers the simulation of the associated character, and then this very character is displayed. As all the features of the character are displayed and present in the environment, their simulation is facilitated as well as the establishment of a match between the simulated character and the displayed character. Accordingly, establishing a match is characterized by the reenactment of the brain activity that occurred during the study phase (Slotnick & Schacter, 2004). By contrast, for the MISMATCH trials, the audio cue triggers the simulation of the associated character, but another character is displayed. As all the distinctive features of the associated character are not displayed or present in the environment, their simulation is needed to establish a mismatch between the simulated character and the displayed character and discriminate them. As such, the discrimination demand is higher for MISMATCH trials than for MATCH trials. Therefore, if one and the same specific memory task contains both MATCH trials and MISMATCH trials, each requiring a different degree of discrimination, then there should be an interaction between trace distinctiveness and the task’s discrimination demand.

We manipulated trace distinctiveness by grouping the characters in blocks of four and manipulating the perceptual distinctiveness between the characters of the same block. Half of the blocks were associated with a LOW DISTINCTIVENESS context, while the other half were associated with a HIGH DISTINCTIVENESS context. In the LOW DISTINCTIVENESS context, the characters of the same block were designed to have many overlapping perceptual features, while in the HIGH DISTINCTIVENESS context they were designed to have very few. In each block, all the characters performed the same type of action (e.g., *sitting on*), but each character performed this action on a different object (character 1: *sitting on a chair*, character 2: *sitting on a bench*, and so on). The type of action was also different from one block to another (block 1: *sitting on*, block 2: *lying down on*, and so on).

According to our hypothesis, the LOW DISTINCTIVENESS context should bias the scale of the memory system towards the simulation of the overlapping features of the characters from the same block as the test character to the detriment of the specific features of the characters (see Brunel et al., 2013). This bias would lead to the emergence of a less rich and specific representation that mainly reflects these overlapping features. However, the diagnostic features for establishing a MISMATCH are exclusively the specific ones while they can be (but not exclusively) the overlapping ones for establishing a MATCH. Consequently, as there are less simulated features, the verification of the diagnostic features would be facilitated for establishing a match than a mismatch in the LOW DISTINCTIVENESS context. Accordingly, we expected performances to be better for the MATCH trials than the MISMATCH trials in the LOW DISTINCTIVENESS context.

By contrast, the HIGH DISTINCTIVENESS context should bias the scale of the memory system towards the simulation of the specific features of the characters in the same block as the test character to the detriment of the overlapping features of the characters. This bias should lead to the emergence of a richer and more specific representation that reflects these specific features. As the diagnostic features for establishing a MISMATCH are exclusively the specific ones, the verification of the diagnostic features would be facilitated for establishing a mismatch than a match in the HIGH DISTINCTIVENESS context. Accordingly, we expected performances to be better for the MISMATCH trials than for the MATCH trials in the HIGH DISTINCTIVENESS context.

Experiment 1

Materials and method

Participants

Thirty-six young adults ($M_{\text{age}} = 19.54$ years, $SD_{\text{age}} = 1.12$ years, 34 female) from Clermont Auvergne University participated in this experiment in exchange for course credit. All the participants had normal or corrected-to-normal vision and audition, and no history of neurological or psychiatric disorders. All the participants were native French speakers.

All experiments reported in this study were carried out in accordance with the recommendations of French Law (Loi Jardé n°2012-300), with written informed consent being obtained from all the subjects in accordance with the Declaration of Helsinki. An ethics approval was issued for the current study by the ethics committee of Clermont Auvergne University (IRB00011540-2019-43).

Material

Character/Action videos *Characters*—Fourteen blocks (two practice blocks, 12 experimental blocks) of four characters were created using The Sims 4™ video game. For half of the blocks assigned to the “LOW DISTINCTIVENESS” context, the characters in each block were designed to be visually lowly distinct from each other. For half of the blocks assigned to the “HIGH DISTINCTIVENESS” context, the characters within each block were designed to be visually highly distinct from each other. The distinctiveness of the characters in each block was configured on the basis of 11 dimensions: gender (man vs. woman), build (heavy vs. light), skin color (blue, red, green, or yellow), age (child vs. adult), hair color (blond, brown, ginger, or white), head covering (beanie, beret, cap, or hat), glasses (with vs. without), sleeve length (short vs. long), pant length (short vs. long), shoes (sneakers vs. flip-flops), and faces.

Within each block in the LOW DISTINCTIVENESS context, the modalities of five dimensions (gender, build, skin color, age, hair color) were identical for the four characters of a given block. For the remaining six dimensions, the modalities were pseudorandomized across the four characters in the block as follows: for a two-modalities dimension, two characters shared the same modality, while for a four-modality dimension, one character was assigned to each modality.

Within each block in the HIGH DISTINCTIVENESS context, the modalities of all 11 dimensions were pseudorandomized across the 4 characters within the block. In this context, only two (not four) modalities of the skin color dimension were assigned in each block. The face of each character was always different in the two contexts. We made sure that none of the characters had the same configuration of modalities as any other character (out of the 260 possible configurations). Of the 14 blocks created, two blocks (one of each context) were selected for practice after changing their skin color modality to black, white, and brown. A screen capture of each character was taken.

Actions—Twelve different types of action were selected (e.g., sitting on, playing) using The Sims 4™ video game. For each type of action, four objects were selected for the performance of the corresponding action (e.g., a chair, a stool, a bench, an armchair). Within each block, the four characters performed the same action but on a different object. The association between actions and distinctiveness context (high vs. low) was counterbalanced between subjects across two lists (A vs. B). For instance, the “Sitting on__” action was presented in the LOW DISTINCTIVENESS context for half of the participants, while this action was presented in the HIGH DISTINCTIVENESS context for the other half. Two additional action types and eight matching objects were included in the practice blocks. A list of actions and objects are available in the [Appendix](#) (Table 4).

Videos—Using The Sims 4™ video game, 48 videos were generated and recorded for Action List A (one for each character) and 48 were recorded for Action List B. Eight additional videos were recorded for the practice blocks using the two additional action types and the eight matching objects added for these blocks. Each video started with a full shot of the motionless character presented in front of the camera for approximately 1 second. The character then moved towards the spectator in the direction of the object, which was not at that time captured by the camera. The camera remained in front of the camera and tracked the character’s movement for approximately 3 seconds. The object appeared in the camera’s range and to the right of the character when the character stopped moving. Finally, the character performed the action on the object for approximately 3 seconds. The scene took place in an empty room with gray walls and floor. On the floor, a path between two blue stripes was always visible and was followed by the character. The average length of the videos was 7.52 seconds ($SD = 1.20$).

Box 1 Photographs of the characters in a block from each distinctiveness context

Audio—For each object, an audio recording was created using Balabolka 2.11 in which a virtual female voice spoke the type of action followed, after a short pause, by the name of the object (e.g., “Sitting on__a CHAIR”). Forty-eight audio tracks were recorded. Eight additional audios were recorded for the practice blocks based on the two additional action types and the eight matching objects included for these blocks.

Procedure

The participants sat in a dark room in front of a computer (≈ 60 cm) with a lamp placed under the table. The experiment was conducted on a Dell OptiPlex 7460 AIO series running Windows 10 pro 64 bit and using OpenSesame 3.2.8 with a screen resolution of $1,980 \times 1,080$ pixels (Mathôt et al., 2012). PyGame was used as a backend to develop, set up and run the experiment. The participants signed the consent form that stated that they were participating in an experiment designed to test their memory. They were then instructed that the experiment would begin with a practice session, followed by two sessions (approx. 15 min. each) separated by a break (approx. 5 min.). Each session started with a study phase (approx. 8 min.), which was followed by a filler task (a memory span task; approx. 2 min.) and finally a test phase (approx. 5 min.). Each session is described below. The total duration of the experiment was approximately 35 minutes. Figure 1 illustrates the experimental procedure.

Session 1

In the study phase, the participants were told that in each trial, they would first see a fixation cross (400 ms) and then hear a voice through their headphones speaking an action and an object name while they simultaneously watched a video of a character performing the action on the object. The participants were asked to pay close attention during each trial and to memorize what the voice said, the appearance of the character, the type of action performed and the object on which it was performed, as they would need to remember this information in the subsequent test phase. They were warned that some characters might look very similar, but that each video

would involve a different character. They were asked to press the space bar within 3 seconds of the end of each video to move on to the next one. The participants saw videos from three LOW and three HIGH DISTINCTIVENESS blocks (24 videos in total) and simultaneously heard the audio track corresponding to each video. Two blocks from the same distinctiveness context were never presented in succession. The presentation order of the blocks and the association between the actions and the distinctiveness contexts (list A vs. B) were counterbalanced across participants. After the study phase, the participants started the memory span task as a filler task.

During the filler phase, the participants performed either the forward or backward memory span task depending on whether they had been assigned an odd or even number. The duration of each memory span task for each participant was similar between sessions (2 minutes). After the filler task, the participants started the test.

In the test phase, the participants were told that in each trial, one of the audio tracks from the study phase (a voice speaking an action and an object name) would be replayed while a neutral gray background was displayed on the screen for 3,000 ms. This would be followed by a photograph of a character from the study phase displayed against a black background in the center of the screen for 1,000 ms. Finally, the gray background would be displayed again and remain on the screen until the participant responded (or until the 4,000-ms time-out). The intertrial interval (ITI) was set to 2,000 ms. The participants were told to indicate, as soon as the character was displayed and as quickly and accurately as possible, whether or not the displayed character corresponded exactly to the character who had performed the action on the specific object whose name they had previously heard (in the study phase). To do this, they pressed one key to answer MATCH and another to answer MISMATCH. They were told that none of the displayed characters were new and that they had all been seen in the study phase. In the MISMATCH trials, the displayed character was from the same block and had performed the same action, but not on the same object, as the target character, who had performed the action on the object mentioned in the audio. In the MATCH trials, the character was the same as the character who had performed the action on the object mentioned in the audio description. Characters were presented only once in both the MISMATCH

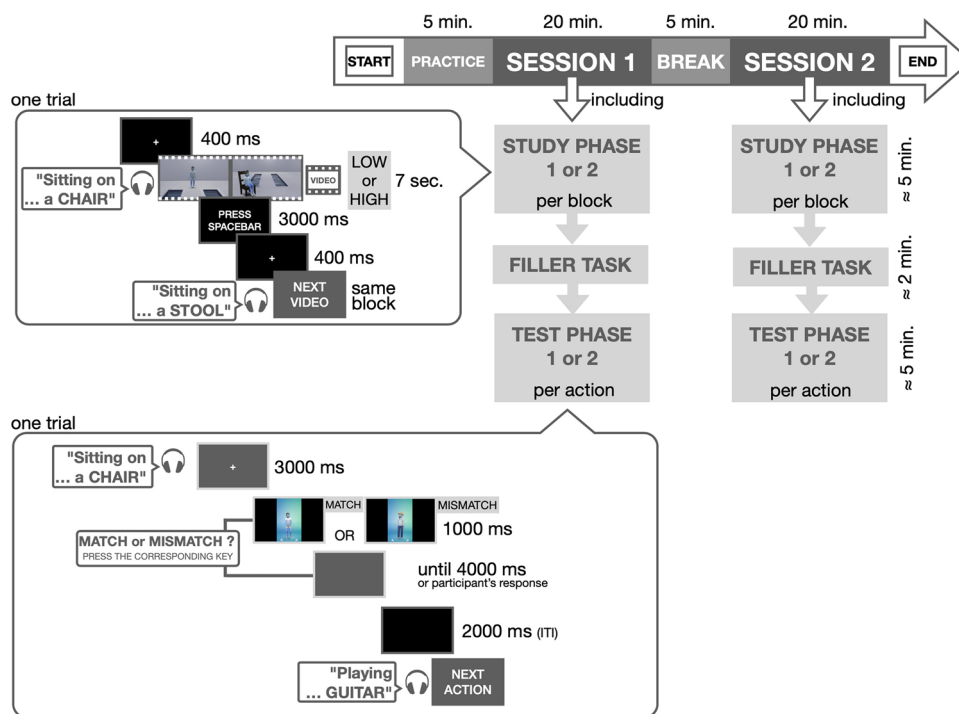


Fig. 1 Diagram of the procedure used in Experiment 1. In each trial of the study phase, participants watched and memorized a video showing a character (in a HIGH or LOW DISTINCTIVENESS context) performing an action on an object, while simultaneously hearing a voice naming the action on the object in question. They then performed a filler task for 2 minutes before the test phase. In each trial of the test phase, the participants heard a voice saying the name of

an action on a given object while looking at a gray screen. They then briefly (1,000 ms) saw the character who had performed this action (MATCH trials) or a different character (MISMATCH trials). A gray screen was then displayed until the participants responded by saying whether or not the displayed character was exactly the same as the one who had performed the action on the object named by the voice. Apart from the material, Sessions 1 and 2 were identical

and MATCH trials. For the 24 trials, the correctness of the association between the audio description and the subsequently presented character in each distinctiveness context was pseudorandomized. The presentation order of these associations was randomized for each participant. For half of the trials, the associations were correct and required a MATCH response and, for the other half, the associations were incorrect and required a MISMATCH response. Accuracy and response times for each trial were collected. After the test phase, there was a 5-minute break before starting the second session.

Session 2

The second session was identical to the first, except that the participants saw the videos they had not seen in the first session and performed the memory span task they had not already completed (forward or backward).

Practice session

The first session was preceded by a practice session which consisted of a practice study phase of eight practice trials (with

material used only in these trials), immediately followed by a practice test phase. There was no interval between the two practice phases as no induction was provided, unlike in experimental sessions one and two). In the practice “study phase,” the first four practice trials consisted in successively presenting the videos of the four characters of the LOW DISTINCTIVENESS practice block together with the corresponding audio tracks, while the next four practice trials consisted in presenting the videos of the four characters of the HIGH DISTINCTIVENESS practice block. The instructions and the trial procedure for the practice study and test phase were identical to those of the study and test phase of the experiment. Feedback (green circle or red cross) on the participants’ performance was only given for the practice test phase and simply indicated whether the response was correct or not.

Results and discussion

Data were analyzed using R (Version 4.0.4) and RStudio (Version 1.2; R Core Team., 2018). The mean response times for correct responses (RT) and the mean rates of

correct responses (CR) were computed across participants for each experimental condition. RT exceeding 3,500 ms and more than three standard deviations above each participant's mean in each condition and RT less than 300 ms and more than three standard deviations below each participant's mean in each condition were considered as outliers and removed from the analyses (less than 5%; see Vallet et al., 2010, for a similar procedure). Two linear mixed-effects models were applied using the *lmerTest* R package (Kuznetsova et al., 2017). One was applied to CR (Table 6) and the other to RT (Table 7). For each analysis, fixed effects were set for “Distinctiveness” (LOW DISTINCTIVENESS vs. HIGH DISTINCTIVENESS) and “Trial type” (MATCH vs. MISMATCH), and their interaction. Participants were included as random intercepts. Degrees-of-freedom method used was Kenward–Roger. Post hoc analyses were performed using the *emmeans* R package (Version 1.6.0). The threshold of statistical significance for all analyses was set to $p < .05$. Sensitivity analyses are reported in Table 5, were computed using the *simr* R package (Green & McLeod, 2016), and showed that the smallest effect size (beta) achievable for the Trial Type \times Distinctiveness interaction is .112 on CRs, and -195 on RTs. Table 1 displays the descriptive statistics.

For CR (Table 6), the analysis revealed a significant main effect of Distinctiveness ($b = -0.260$, $SE = 0.025$, $t = -8.257$, $p < .001$, 95% CI $[-0.32, -0.2]$), with higher CR in the HIGH DISTINCTIVENESS context than in the LOW DISTINCTIVENESS context. The analysis also revealed a significant main effect of Trial type ($b = -0.206$, $SE = 0.032$, $t = -6.546$, $p < .001$, 95% CI $[-0.27, -0.14]$), with higher CR for the MISMATCH trials than for the MATCH trials. Finally, the interaction between Distinctiveness and Trial type was also significant, ($b = 0.312$, $SE = 0.045$, $t = 6.996$, $p < .001$, 95% CI $[0.22, 0.4]$). Post hoc comparisons showed higher CR for the MISMATCH trials than for the MATCH trials in the HIGH DISTINCTIVENESS context, $t(1665) = 6.546$, $p < .0001$, 95% CI $[0.145, 0.2685]$, and higher CR for the MATCH trials than for the MISMATCH trials in the LOW DISTINCTIVENESS context, $t(1665) = -3.347$, $p < .001$, 95% CI $[-0.168, -0.0437]$ (Fig. 2).

Table 1 Descriptive statistics of Experiment 1

Trials	Distinctiveness	Correct responses		Response time	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
MISMATCH	HIGH	0.81	0.14	1,374	377
	LOW	0.55	0.18	1,694	464
MATCH	HIGH	0.60	0.16	1,413	436
	LOW	0.66	0.18	1,530	462

Means and standard deviations per condition and per participant are displayed (unadjusted for the linear mixed model). *SD* = standard deviation. Response times are in milliseconds

For RT (Table 7), the analysis revealed a significant main effect of Distinctiveness ($b = 314.65$, $SE = 49.05$, $t = 6.415$, $p < .001$, 95% CI $[218.53, 410.71]$), with faster RT in the HIGH DISTINCTIVENESS context than in the LOW DISTINCTIVENESS context. The main effect of Trial type was not significant ($b = 49.73$, $SE = 47.23$, $t = 1.053$, $p = .293$, 95% CI $[-42.81, 142.24]$). The analysis also revealed a significant interaction between Distinctiveness and Trial type ($b = -208.90$, $SE = 69.77$, $t = -2.994$, $p < .01$, 95% CI $[-345.5, -72.11]$). Post hoc comparisons showed no difference between MISMATCH trials and MATCH trials in the HIGH DISTINCTIVENESS context ($p > .1$), but faster RT for the MATCH trials than for the MISMATCH trials in the LOW DISTINCTIVENESS context, $t(1054) = 3.099$, $p = .002$, 95% CI $[58.4, 260]$ (Fig. 3).

The aim of Experiment 1 was to test the hypothesis that distinctiveness interacts with the discrimination required for a specific memory task on MATCH versus MISMATCH (mismatch) trials. More precisely, the objective was to determine whether trace distinctiveness influences trace discriminability and the specificity of the emerging representation of the character. It was expected that the LOW DISTINCTIVENESS context should promote the simulation of the overlapping features of characters to the detriment of their specific features. This should make it easier to find a match between the test character and the simulated character (MATCH trials) than to discriminate between them (MISMATCH trials). Conversely, the HIGH DISTINCTIVENESS context should promote the simulation of the specific features of the characters, making it easier to discriminate (i.e., find a mismatch) between the test character and the simulated character (MISMATCH trials) than to find a match (MATCH trials).

The analysis showed higher CR for the MISMATCH trials than for the MATCH trials in the HIGH DISTINCTIVENESS context and, concomitantly, also revealed higher CR and faster RT for the MATCH trials than for the MISMATCH trials in the LOW DISTINCTIVENESS context.

These results support the hypothesis that the degree of discrimination required to perform a more or less specific memory task differs. In other words, the more the task requires the emergence of specific representations, the more the system must discriminate between memory traces in order to simulate the specific features of the items. To test whether the distinctiveness context induces a type of simulation outcome (either specific features for high distinctiveness or overlapping features for low distinctiveness) that is beneficial or detrimental depending on the type of trial, it is necessary to manipulate the sensorimotor simulation more directly. To manipulate the sensorimotor simulation, it is possible to interfere with the simulation of the sensorimotor features of the traces during the emergence of the representation (e.g., Purkart et al., 2019; Vallet et al., 2010).

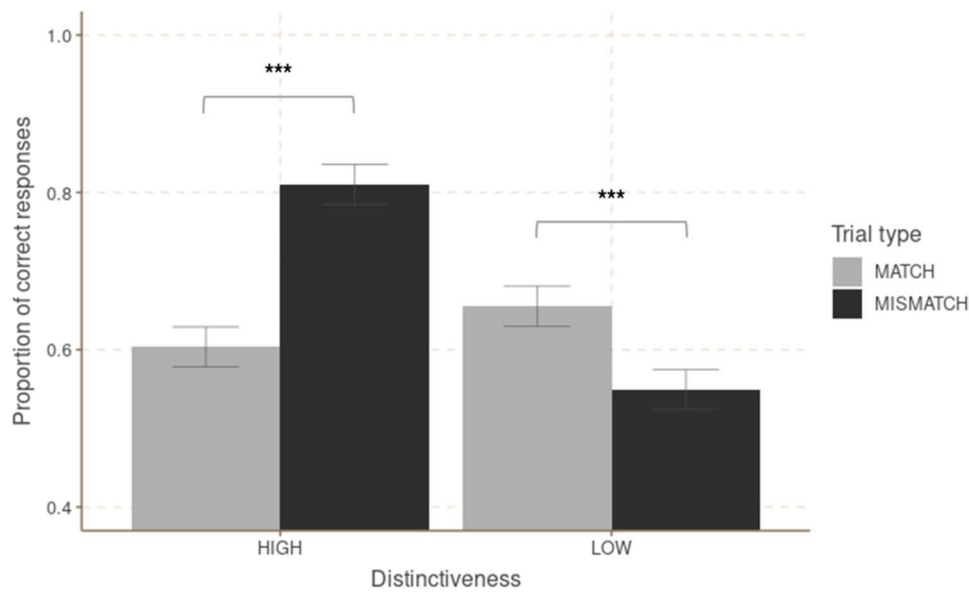


Fig. 2 Comparison of correct response rates in each Distinctiveness context (HIGH vs. LOW) for the different Trial type (MISMATCH vs. MATCH). Gray bars represent standard errors corrected for the

within-participant design. Means and standard errors adjusted for the linear mixed model are displayed

Several studies including some of our team have previously used sensory interference/facilitation paradigms to influence sensorimotor simulations. For instance, these studies have used visual noise (Purkart et al., 2019; Rey et al., 2015; Vallet et al., 2010, 2013a, b), white noise (Brunel et al., 2010b; see also Brunel, 2013), posture (Dutriaux & Gyselinck, 2016; Yee et al., 2013), and taste (Riou et al., 2015) as sources of interference. The effects of interference were measured in

nondiscriminating memory activities (e.g., categorizing a stimulus as a manufactured object or as a living being), as well as in discriminating memory activities (e.g., recalling a list of words). The global rationale of this approach is that if a significant overlap between perceptual and memory mechanisms exists (e.g., if categorizing/remembering a stimulus relies on the simulation/recreation of the neuronal state elicited during its perception), a perceptually present

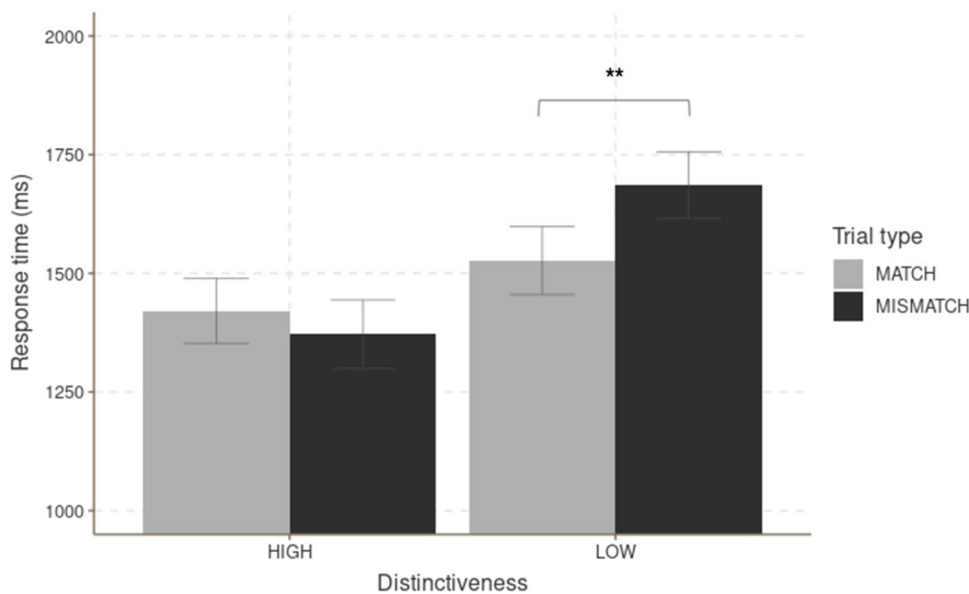


Fig. 3 Comparison of response times in each Distinctiveness context (HIGH vs. LOW) for the different Trial types (MISMATCH vs. MATCH). Gray bars represent standard errors corrected for the

within-participant design. Means and standard errors adjusted for the linear mixed model are displayed

interfering stimulus, as well as a perceptually absent, but simulated interfering stimulus, should interfere with the current memory activity (and the underlying simulation) or facilitate it depending on the circumstances. Since many results have already confirmed these predictions, a similar approach was taken in Experiment 2a by using an interfering visual stimulus to interfere with the simulation of the sensorimotor features of the traces during the emergence of the representation.

Experiment 2a

The aim of Experiment 2a was to manipulate the sensorimotor mechanism in order to investigate whether the interaction between the distinctiveness context and the trial type is underpinned by the type of simulation outcome induced by the distinctiveness context. As in Experiment 1, trace distinctiveness was manipulated through the visual sensory features of the characters, meaning that interfering with the simulation of specific sensory features would lead to contrasting effects as a function of trace distinctiveness and trial type. More specifically, if a HIGH DISTINCTIVENESS context biases the scale toward a simulation of specific features that is beneficial for MISMATCH (but not MATCH) trials, then interfering with the simulation of specific sensory features of the characters should reduce this bias and be detrimental only for MISMATCH trials. However, according to the scale hypothesis, reducing this bias by means of interference should also lead to an increase in the bias toward the simulation of overlapping features. Thus, if a LOW DISTINCTIVENESS context biases the scale toward a simulation of overlapping features that is beneficial to MATCH (but not MISMATCH) trials, then the interference should increase this bias and be beneficial only for MATCH trials. To test this hypothesis, we used a sensory masking paradigm to interfere with the simulation of visual features of the characters when the audio track triggered the simulation of the character during the test phase (Purkart et al., 2019; Vallet et al., 2010). Sensory masking means adding noise to the sensory processing and thus reducing sensory resolution. Since higher resolution makes it possible for more traces to be distinct (Ekstrom & Yonelinas, 2020; Mille et al., 2021), sensory masking reduces the specificity of the simulation.

Materials and method

Participants

Thirty-two young adults ($M_{\text{age}} = 19.13$ years, $SD_{\text{age}} = .94$ years, 31 female) from Clermont Auvergne University participated in this experiment in exchange for course credit. All the participants had normal or corrected-to-normal vision and audition, and no history of neurological or psychiatric

disorders. All the participants were native French speakers. None of these participants had taken part in Experiment 1.

Material

The material of this experiment was the same as that of Experiment 1, except that half of the tests in the test phase were presented with a dynamic visual noise (DVN; McConnell & Quinn, 2004) in order to interfere with the simulation of the character's specific features (Purkart et al., 2019). The other half of the trials were presented with a noninterfering control stimulus (Purkart et al., 2019).

Dynamic visual noise (DVN) Five different 5-s DVN clips were created using the available source code provided by McConnell and Quinn (2004), as was also done by Sheldon et al. (2016). The DVN clips consisted of a matrix of randomly moving black and white squares. This created a continuously changing pattern that passively engaged the participants' visuospatial processes and interfered with their visual mental imagery. The DVNs were presented on a 21.5-inch computer screen (1,920 × 1,080 pixels).

Noninterfering control stimulus A noninterfering control stimulus was created and consisted of a gray screen (Hex color code #CCCCCC). This was presented on a 21.5-inch computer screen (1,920 × 1,080 pixels).

Procedure

The procedure was identical to Experiment 1, except that the filler task was replaced by a countdown task. In addition, for half of the trials in the test phase, the gray square (noninterfering control stimulus) presented before and after the photograph of the character was replaced by a DVN. Moreover, in the LOW DISTINCTIVENESS context of Experiment 1, the characters' features overlapped so much that the specificity of the emerging representation of the character was reduced to the point where the effect of the mask might have been unable to further enhance the match between the simulated character and the test character. Indeed, CR rates for the LOW DISTINCTIVENESS context on the MISMATCH trials did not exceed the chance threshold (lower CL = .49). To make it possible to observe an effect of the sensory mask, Experiment 2a was spread over three sessions rather than two in order to increase CR rates. Figure 4 illustrates the experimental procedure.

Results and discussion

The data were analyzed using the same procedure as that used in Experiment 1. Two linear mixed-effects models were applied using the *lmerTest* R package (Kuznetsova et al.,

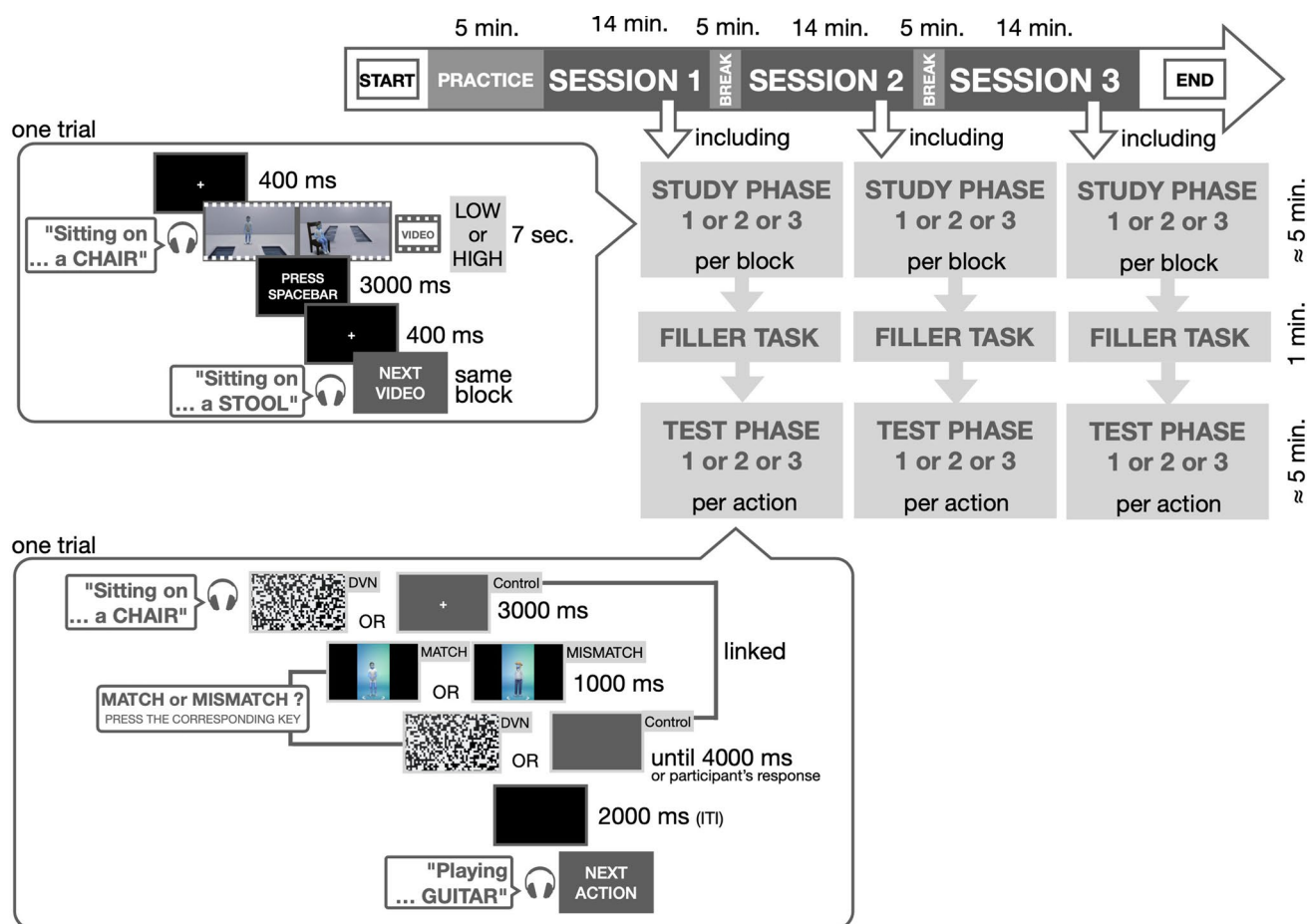


Fig. 4 Diagram of the procedure used in Experiment 2a. In each trial of the study phase, participants watched and memorized a video showing a character (in a HIGH or LOW DISTINCTIVENESS context) performing an action on an object, while simultaneously hearing a voice saying the name of the action on the object in question. They then performed a filler task 1 minute before the test phase. In each trial of the test phase, the participants heard a voice naming an action on a given object while seeing a gray screen (control interference) or

a dynamic visual noise (DVN interference). They then briefly (1,000 ms) saw the character who had performed this action (MATCH trials) or a different character (MISMATCH trials). A gray screen or a DVN was then displayed until the participants responded by saying whether or not the displayed character was exactly the same as the one who had performed the action on the object named by the voice. Apart from the material, Sessions 1, 2, and 3 were identical

2017). One was applied to CR (Table 8) and the other to RT (Table 9). For each analysis, fixed effects were set for “Distinctiveness” (LOW DISTINCTIVENESS vs. HIGH DISTINCTIVENESS), “Trial type” (MATCH vs. MISMATCH), “Interference” (DVN vs. Control), and their interaction. Participants were included as random intercepts. Sensitivity analyses are reported in Table 5, were computed using the *simr* R package (Green & McLeod, 2016), and showed that the smallest effect size (beta) achievable for the Trial Type \times Distinctiveness interaction on CRs is .130, and -320 for the Trial Type \times Distinctiveness \times Interference interaction on RTs. Table 2 displays the descriptive statistics.

For CR (Table 8), the analysis revealed a significant main effect of Distinctiveness ($b = -0.198$, $SE = 0.046$, $t = -4.300$, $p < .001$, 95% CI $[-0.288, -0.108]$), with higher CR in the HIGH DISTINCTIVENESS context than in the

LOW DISTINCTIVENESS context. The analysis also revealed no significant main effect of Trial type and Interference ($p > .1$). However, the analysis revealed a significant interaction between Distinctiveness and Trial type ($b = 0.260$, $SE = 0.065$, $t = 4.001$, $p < .001$, 95% CI $[-0.133, 0.388]$). Post hoc comparisons showed higher CR for the MISMATCH trials than for the MATCH trials in the HIGH DISTINCTIVENESS context, $t(1497) = 2.321$, $p = .020$, 95% CI $[0.0117, 0.139]$, and higher CR for the MATCH trials than for the MISMATCH trials in the LOW DISTINCTIVENESS context, $t(1497) = -6.082$, $p < .0001$, 95% CI $[-0.2618, -0.134]$. The other interactions were not significant ($p > .1$) (Fig. 5).

For RT (Table 9), the analysis revealed a significant main effect of Distinctiveness ($b = 133.576$, $SE = 66.710$, $t = 2.002$, $p < .05$, 95% CI $[3.133, 263.963]$), with faster RT in

Table 2 Descriptive statistics of Experiment 2a

Trials	Distinctiveness	Interference	Correct responses		Response time	
			<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
MISMATCH	HIGH	DVN	0.76	0.21	1,293	471
		CONTROL	0.78	0.20	1,135	394
	LOW	DVN	0.56	0.22	1,415	457
		CONTROL	0.53	0.23	1,454	628
MATCH	HIGH	DVN	0.70	0.20	1,244	427
		CONTROL	0.69	0.22	1,301	523
	LOW	DVN	0.76	0.16	1,363	537
		CONTROL	0.72	0.17	1,315	557

Means and standard deviations per condition and per participant are displayed (unadjusted for the linear mixed model). *SD* = standard deviation. Response times are in milliseconds

the HIGH DISTINCTIVENESS context than in the LOW DISTINCTIVENESS context. The main effect of Trial type was not significant ($p > .1$), while the main effect of Interference was significant, with faster RT in the Control Interference condition than in the DVN condition ($b = -149.847$, $SE = 60.977$, $t = -2.457$, $p < .02$, 95% CI $[-269.056, -30.642]$). The analysis revealed a nonsignificant interaction between Distinctiveness and Trial type ($b = -24.563$, $SE = 91.186$, $t = -0.269$, $p = .788$, 95% CI $[-202.772, 153.760]$). However, based on the results of Experiment 1 and a priori hypotheses, post hoc comparisons were conducted and showed faster RT for MISMATCH trials and MATCH trials in the HIGH DISTINCTIVENESS context with a difference close to significance, $t(992) = -1.881$, $p = .060$, 95% CI $[-170.59, 3.59]$, but faster RT for the MATCH trials than for the MISMATCH trials in the LOW

DISTINCTIVENESS context, $t(992) = 2.010$, $p < .05$, 95% CI $[2.28, 189.57]$. Interaction between Distinctiveness and Interference was significant ($b = 203.432$, $SE = 94.871$, $t = 2.144$, $p < .04$, 95% CI $[18.009, 388.948]$). However, post hoc comparisons showed no significant differences between the DVN and the Control Interference condition both in the HIGH and LOW DISTINCTIVENESS contexts ($p > .01$). The analysis revealed a significant interaction between Trial type and Interference ($b = 179.700$, $SE = 88.306$, $t = 2.035$, $p < .05$, 95% CI $[7.033, 352.302]$). However, post hoc comparisons showed no significant differences between the DVN and the Control Interference condition both for MATCH and MISMATCH trials ($p > .01$). The analysis also revealed a significant two-way Distinctiveness \times Trial Type \times Interference interaction ($b = -309.719$, $SE = 129.783$, $t = -2.386$, $p < .02$, 95% CI $[-563.476, -56.035]$). Post hoc comparisons only

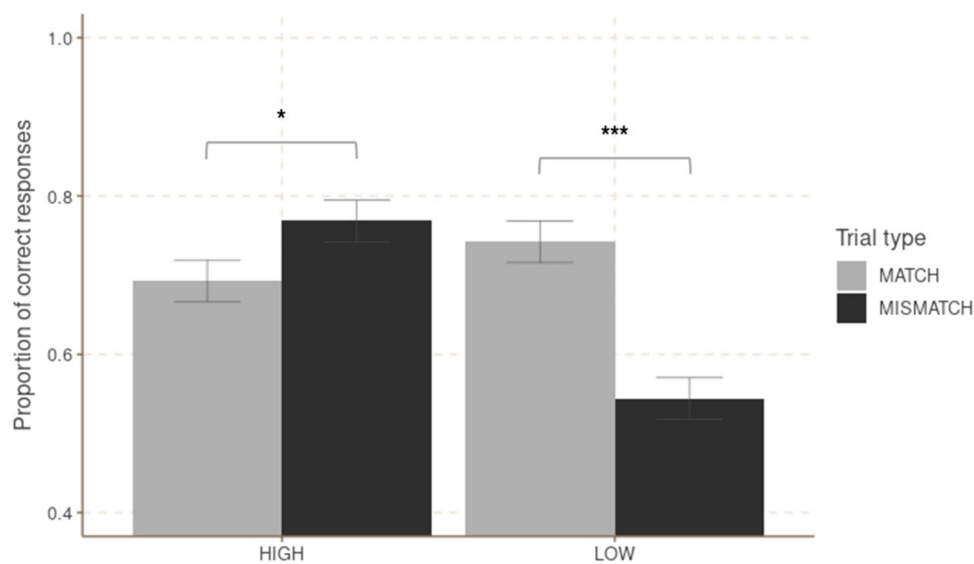


Fig. 5 Comparison of correct response rates in each Distinctiveness context (HIGH vs. LOW) for the different Trial type conditions (MISMATCH vs. MATCH). Gray bars represent standard errors corrected

for the within-participant design. Means and standard errors adjusted for the linear mixed model are displayed

showed slower RT in the DVN than in the Control Interference condition for MISMATCH trials in the HIGH DISTINCTIVENESS context, $t(991) = 2.457, p < .02, 95\% \text{ CI } [30.2, 269.5]$. This comparison was not significant for the MATCH trial type ($p > .1$). These comparisons were also not significant in the LOW DISTINCTIVENESS context ($p > .1$) (Fig. 6).

The aim of Experiment 2a was to manipulate the sensorimotor mechanism by using a DVN in order to investigate whether the interaction between the distinctiveness context and the trial type is underpinned by the type of simulation outcome induced by the distinctiveness context. We hypothesized that the DVN would lead to contrasting effects as a function of distinctiveness context and trial type. More specifically, the DVN should be detrimental only for MISMATCH trials in a HIGH DISTINCTIVENESS context because this context should bias the scale toward the simulation of specific features in a way that is beneficial for MISMATCH (but not MATCH) trials. Moreover, the DVN should be beneficial only for MATCH trials in a LOW DISTINCTIVENESS context because this context biases the scale toward the simulation of overlapping features, which is beneficial for MATCH (but not MISMATCH) trials.

As in Experiment 1, the analysis of Experiment 2a showed higher CR and faster RT for the MATCH than for the MISMATCH trials in the LOW DISTINCTIVENESS context. This suggests that the LOW DISTINCTIVENESS context actually promotes the simulation of overlapping features rather than specific features of the characters and thus biases the simulation towards overlapping features (less discrimination). Moreover, as in Experiment 1, the analysis of Experiment 2a showed marginally higher CR for the MISMATCH than for the MATCH trials in the HIGH DISTINCTIVENESS context. This suggests that the

HIGH DISTINCTIVENESS context actually promotes the simulation of specific rather than overlapping features of the characters and thus biases the simulation towards specific features (more discrimination).

Interestingly, DVN did not have a significant main effect on CR and RT but did have a detrimental effect for MISMATCH trials but only in the HIGH DISTINCTIVENESS context. Indeed, slower RTs were observed in the DVN than in the Control Interference condition in the HIGH DISTINCTIVENESS context for MISMATCH trials. This result confirms that the simulation was influenced by the DVN, which shifted the scale towards the simulation of the overlapping features of the characters by interfering with the simulation of the specific features, thus leading to the emergence of a low specificity representation of the character. At the same time, and contrary to our hypothesis, the DVN did not increase the advantage of LOW DISTINCTIVENESS for the MATCH trials (for either CRs or RTs). This would appear to be due to the fact that the characters in the LOW DISTINCTIVENESS blocks were already insufficiently distinctive for the DVN to shift the scale by reducing the simulation of specific features. In other words, the scale was too biased toward the simulation of overlapping features for the DVN to be beneficial. Despite the change from two to three sessions, the performances were not above the chance threshold for the MISMATCH trials in the LOW DISTINCTIVENESS context (lower CL = .492). Participants might have found it too difficult to discriminate between the characters of the LOW DISTINCTIVENESS blocks.

The aim of the following Experiment 2b was to enhance the distinctiveness of all the characters in order to determine whether the DVN induces beneficial effects for MATCH

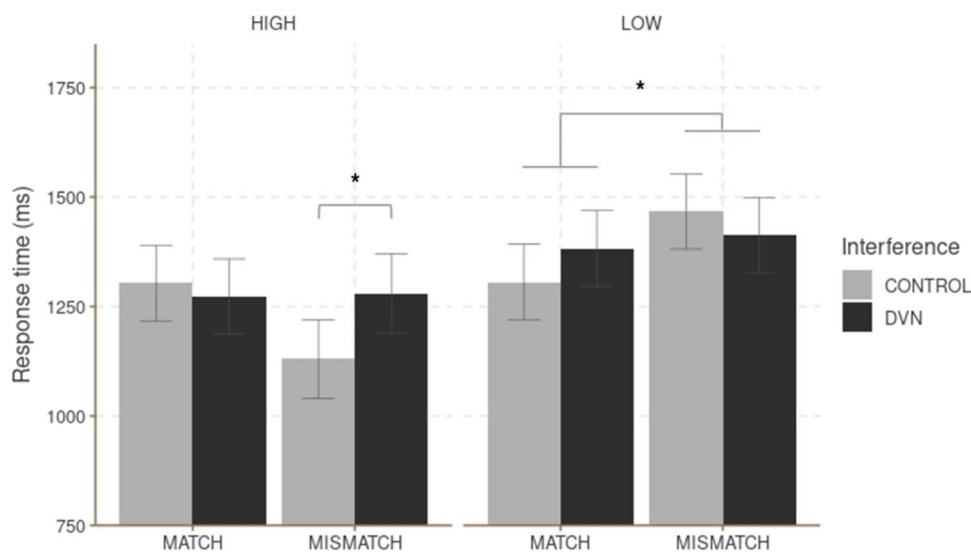


Fig. 6 Comparison of response times in each Distinctiveness context (HIGH vs. LOW) for the different Trial type (MISMATCH vs. MATCH) and Interference (DVN vs. Control) conditions. Gray bars

represent standard errors corrected for the within-participant design. Means and standard errors adjusted for the linear mixed model are displayed

trials in a LOW DISTINCTIVENESS context in which the characters do not already induce a strong bias toward the simulation of the overlapping features.

Experiment 2b

The aim of Experiment 2b was the same as that of Experiment 2a. However, in this new experiment, character distinctiveness was better manipulated for. Given that distinctiveness is not an intrinsic feature of stimuli but a phenomenon emerging from the contrast between stimuli (Hunt, 2013; Hunt et al., 2006; Oker & Versace, 2014; Surprenant & Neath, 2009), the HIGH DISTINCTIVENESS context of Experiment 2a became the LOW DISTINCTIVENESS context (named NEWLOW context) in Experiment 2b and was contrasted with a new, more distinctive context (named NEWHIGH DISTINCTIVENESS context). Since overall character distinctiveness was increased in Experiment 2b, we expected the NEWLOW DISTINCTIVENESS context to reduce the bias toward the simulation of the overlapping features observed in Experiment 1 and 2a in the LOW DISTINCTIVENESS context and make it easier to observe beneficial DVN effects for MATCH trials in this context.

Because the characters in the NEWHIGH DISTINCTIVENESS context were contrasted with more overlapping characters (NEWLOW DISTINCTIVENESS context), they should have been more distinctive, thus leading to a significant trial type effect, with participants finding it easier to identify a MISMATCH than a MATCH. Thus, the predicted DVN effects for the NEWHIGH DISTINCTIVENESS context were the same as the predicted DVN effects for the HIGH DISTINCTIVENESS context in Experiment 2a. Indeed, DVN was expected to interfere with the simulation of the specific features of the characters and be detrimental in MISMATCH trials (but not in MATCH trials).

Materials and method

Participants

Thirty-six young adults ($M_{\text{age}} = 19.54$ years, $SD_{\text{age}} = 2.97$ years, 31 female) from Clermont Auvergne University participated in this experiment in exchange for course credit. All the participants had normal or corrected-to-normal vision and audition, and no history of neurological or psychiatric disorders. All the participants were French native speakers. None of these participants had taken part in either Experiment 1 or Experiment 2a.

Material

The material for this experiment was the same as for Experiment 2a, except that the visual distinctiveness of the

characters was increased by creating two new distinctiveness contexts (NEWLOW and NEWHIGH).

Character/Action videos *Characters*—Fourteen blocks (two practice blocks, 12 experimental blocks) of four characters were created using The Sims 4™ video game. For half of the blocks assigned to the “NEWLOW DISTINCTIVENESS” context, the characters in each block were designed to be visually moderately distinct from each other. For half of the blocks assigned to the “NEWHIGH DISTINCTIVENESS” context, the characters in each block were designed to be visually highly distinct from each other. In this context, each character possessed rare and highly specific visual features.

The distinctiveness of the characters in each block was configured on the basis of 11 dimensions: gender (man vs. woman), build (heavy vs. light), skin color (only blue, red, green, yellow for the NEWLOW DISTINCTIVENESS context, and blue, red, green, yellow, purple, orange, gray, or pink for the NEWHIGH DISTINCTIVENESS context), age (child vs. adult), hair color (only blond, brown, ginger, white for the NEWLOW DISTINCTIVENESS context, and blond, brown, ginger, white, blue, red, green, yellow, purple, orange, gray, or pink for the NEWHIGH DISTINCTIVENESS context), head covering (beanie, beret, cap, or hat), glasses (with vs. without), sleeve length (short vs. long), pant length (short vs. long), shoes (sneakers vs. flip-flops), and faces.

Within each block in the NEWHIGH DISTINCTIVENESS context, the modalities of all 11 dimensions were pseudorandomized across the four characters within the block. In each block of the corresponding context, each character had a unique skin color, including two colors that were not used for the NEWLOW DISTINCTIVENESS context (i.e., purple, orange, pink, gold, gray). All of the color features (i.e., skin, clothes and hair) were presented in a single color for two out of four characters. In addition, the two characters that did not have a unique color wore more complex and unique clothes than those in the NEWLOW DISTINCTIVENESS context (e.g., different colored T-shirt with logo rather than a simple white T-shirt with no logo in the NEWLOW DISTINCTIVENESS context). The face of each character was always different in both contexts. We ensured that no character had the same configuration of features as any other character. Of the 14 blocks created, two blocks were selected for practice. The practice blocks were the same as Experiments 1 and 2. A photograph was taken of each character.

Actions and videos—The actions were the same as those used in Experiments 1 and 2. The videos were created following the same procedure as used in Experiments 1 and 2. The average length of the videos was 7.5 seconds ($SD = 1.37$).

DVN noninterfering control stimulus—The same DVN and noninterfering control stimulus as in Experiment 2a were used.

Box 2 Photographs of the characters in a block in each distinctiveness context

Procedure

The procedure was the same as Experiment 2a, except that the correctness of the trials of the test phases was controlled as follows for the MISMATCH trials in order to promote specific versus categorical processing. In the NEWHIGH DISTINCTIVENESS context, the test character had three or four features that differed from those of the correct studied character on the features of gender, body, skin and age, and, when the correct character was presented in a single color, the test character was not, and vice versa. In the NEWLOW DISTINCTIVENESS context, the test character had one or two features that differed from those of the correct studied character on the features of gender, body, skin and age.

Results and discussion

The data were analyzed using the same procedure as that used in Experiments 1 and 2a. Two linear mixed-effects models were applied using the *lmerTest* R package (Kuznetsova et al., 2017). One was applied to CR (Table 10) and the other to RT (Table 11). For the analysis on CR, fixed effects were only set for “Distinctiveness” (NEWLOW DISTINCTIVENESS vs. NEWHIGH DISTINCTIVENESS), “Trial type” (MATCH vs. MISMATCH), and their interaction. The fixed effect was not set for “Interference” (DVN vs. Control) in this analysis as no main effect or interaction were expected based on the results of Experiment 2a.¹ For the analysis on RT, fixed effects were set for “Distinctiveness” (NEWLOW DISTINCTIVENESS vs. NEWHIGH DISTINCTIVENESS), “Trial type” (MATCH vs. MISMATCH), and “Interference” (DVN vs. Control), and their interaction. Participants were included as random intercepts. Sensitivity analyses are reported in Table 5, were computed using the *simr* R package (Green & McLeod, 2016), and showed that the smallest effect size (beta) achievable for the Trial Type × Distinctiveness interaction on CRs is .109, and −64 for the

Trial Type × Distinctiveness × Interference interaction on RTs. Table 3 displays the descriptive statistics.

For CR (Table 10), the analysis revealed a significant main effect of Distinctiveness ($b = 0.113$, $SE = 0.029$, $t = 3.918$, $p < .001$, 95% CI [0.056, 0.170]), with higher CR in the NEWHIGH DISTINCTIVENESS context than in the NEWLOW DISTINCTIVENESS context. The analysis revealed no significant main effect of Trial type and a significant interaction between Distinctiveness and Trial type ($b = -0.115$, $SE = 0.041$, $t = -2.828$, $p < .01$, 95% CI [−0.195, −0.035]). Post hoc comparisons showed higher CR for MISMATCH than for MATCH trials in the NEWHIGH DISTINCTIVENESS context, $t(1665) = 3.347$, $p < .001$, 95% CI [0.0398, 0.1526]. This comparison was not significant in the NEWLOW DISTINCTIVENESS context ($p > .1$) (Fig. 7).

For RT (Table 11), the analysis revealed a main effect of Trial type close to significance ($b = -105.42$, $SE = 55.73$, $t = -1.892$, $p = .059$, 95% CI [−214.48, 3.518]), with faster RT in MISMATCH trials than in MATCH trials. The main effect of Distinctiveness was not significant ($p > 1$) and neither was the main effect of Interference ($p > 1$). The analysis revealed a significant interaction between Distinctiveness and Trial type ($b = 154.82$, $SE = 77.38$, $t = 2.001$, $p = .046$, 95% CI [3.548, 306.230]). Post hoc comparisons showed no significant differences between MISMATCH and MATCH trials in the NEWLOW DISTINCTIVENESS context while they showed slower RT for MATCH than for MISMATCH trials in the NEWHIGH DISTINCTIVENESS context with a difference close to significance, $t(1215) = -1.802$, $p = .072$, 95% CI [−33.9, 6.05]. However, the analysis did not reveal a significant interaction between Distinctiveness and Interference or between Trial type and Interference, nor between Distinctiveness, Trial type, and Interference ($p > .1$).

However, in the light of our hypothesis and analysis of Experiment 2a, this two-way interaction was decomposed and a post hoc analysis was performed. Post hoc analysis showed faster RT in the DVN than in the Control Interference condition for MATCH trials in the NEWLOW DISTINCTIVENESS context, $t(1215) = -2.060$, $p = .039$, 95% CI [−220.4, −5.36]. This comparison was not significant for the MISMATCH trial type in the NEWLOW

¹ For an analysis with Interference as fixed effect, see Table 12. This analysis confirms no main effect of or interaction with the Interference fixed effect.

Table 3 Descriptive statistics of Experiment 2b

Trials	Distinctiveness	Interference	Correct responses		Response time	
			M	SD	M	SD
MISMATCH	NEWHIGH	DVN	0.82	0.16	1271	496
		CONTROL	0.84	0.19	1122	348
	NEWLOW	DVN	0.72	0.22	1316	436
		CONTROL	0.72	0.19	1275	508
MATCH	NEWHIGH	DVN	0.72	0.21	1316	490
		CONTROL	0.75	0.20	1221	480
	NEWLOW	DVN	0.72	0.20	1194	401
		CONTROL	0.76	0.23	1353	604

Means and standard deviations per condition and per participant are displayed (unadjusted for the linear mixed model). *SD* = standard deviation. Response times are in milliseconds

DISTINCTIVENESS context ($p > .1$). Post hoc analysis also showed slower RT in the DVN than in the Control Interference condition for MISMATCH trials in the NEWHIGH DISTINCTIVENESS context, $t(1214) = 2.275, p = .023, 95\% \text{ CI } [16.2, 219.73]$, and this comparison was not significant for the MATCH trial type in the NEWHIGH DISTINCTIVENESS context ($p > .1$) (Fig. 8).

The aim of Experiment 2b was to investigate whether a DVN produces opposing effects depending on the DISTINCTIVENESS context and the trial type (by increasing the distinctiveness of the characters of Experiment 2a). This would result in an increase in the benefit of the NEWLOW DISTINCTIVENESS context for the MATCH trials, combined with a decrease in the benefit of the NEWHIGH DISTINCTIVENESS context for the MISMATCH trials.

As in Experiments 1 and 2a, participants’ CR rates were higher for the MISMATCH trials than for the MATCH trials in the NEWHIGH DISTINCTIVENESS context. This suggests that the NEWHIGH DISTINCTIVENESS context still biased the simulation of the specific features of the characters rather than the overlapping features, and thus promoted a high level of discrimination between the memory traces.

However, unlike in Experiments 1 and 2a, the CR rates of the participants did not differ between the MATCH trials and MISMATCH trials in the NEWLOW DISTINCTIVENESS context. This suggests that the NEWLOW DISTINCTIVENESS context promoted the simulation of specific and overlapping features equally. In Experiment 2b, the contrast between the NEWLOW DISTINCTIVENESS characters and the NEWHIGH DISTINCTIVENESS characters provided optimum conditions for

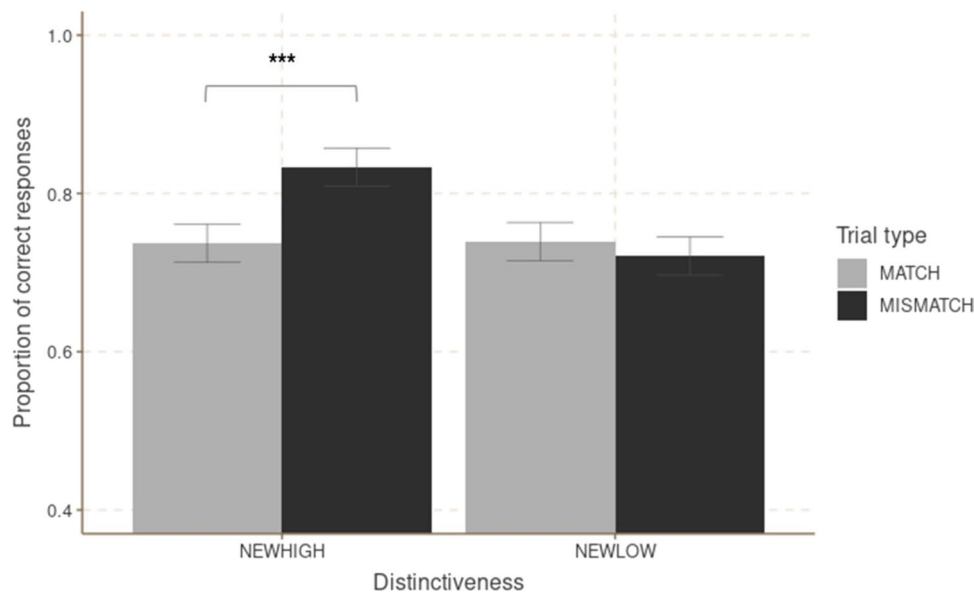


Fig. 7 Comparison of correct response rates in each Distinctiveness context (NEWHIGH vs. NEWLOW) for the different Trial type conditions (MISMATCH vs. MATCH). Gray bars represent standard

errors corrected for the within-participant design. Means and standard errors adjusted for the linear mixed model are displayed

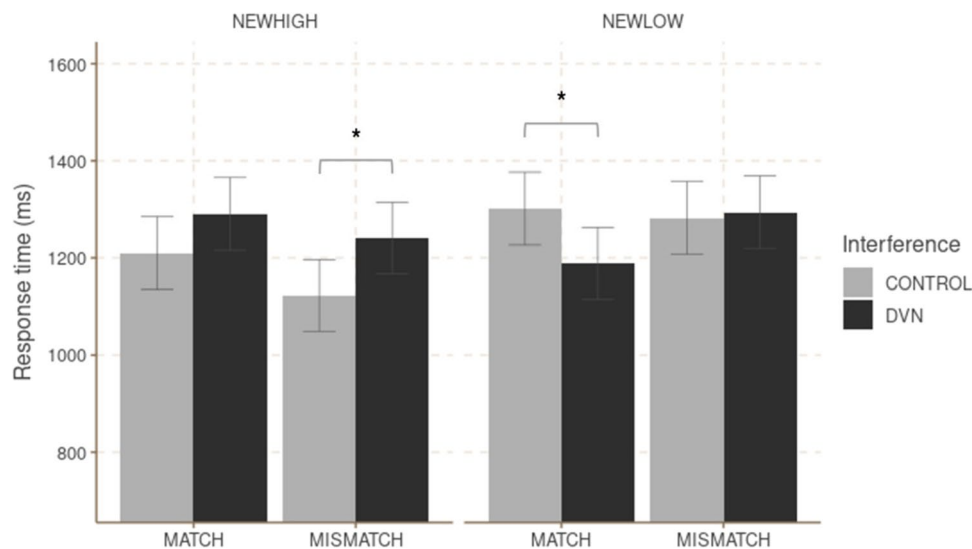


Fig. 8 Comparison of response times in each Distinctiveness context (HIGH vs. LOW) for the different Trial type (MISMATCH vs. MATCH) and Interference (DVN vs. Control) conditions. Gray bars

represent standard errors corrected for the within-participant design. Means and standard errors adjusted for the linear mixed model are displayed

the DVN to promote the simulation of the overlapping features and to shift the scale towards the simulation of the overlapping features of the memory traces (less discrimination).

As predicted by our main hypothesis, the participants' responses were (1) slower in the DVN than in the Control Interference condition in the NEWHIGH DISTINCTIVENESS context for MISMATCH trials, but not for MATCH trials; (2) faster in the DVN than in the Control Interference condition in the NEWLOW DISTINCTIVENESS context for MATCH trials, but not for MISMATCH trials. These results reveal that the DVN had opposite effects depending on the DISTINCTIVENESS context and the trial type, thus confirming that the DVN promotes the simulation of overlapping features by reducing the simulation of specific features.

Taken together, the results of Experiment 2b support the hypothesis that the specificity of the emerging representation of the character depends on trace distinctiveness operating through the simulation of specific features of the memory traces. Thus, the interaction between distinctiveness and trial type is explained by the simulation of specific sensory features of the characters.

General discussion

The aim of this study was to examine the hypothesis of a continuum of representation specificity emerging from a single memory system that accumulates traces of specific experiences. This continuum of specificity is assumed to reflect a scale whose equilibrium depends on the outcome of the simulation, each side corresponding to the semantic/abstract representations or the episodic ones. The greater trace distinctiveness is, the more biased the scale will be towards the simulation of specific

features (involving few traces) to the detriment of the overlapping features of the traces (involving many traces), and the more specific the emerging representation will be, and vice versa. Given that the same specific memory task can have a varying discrimination demand and consequently a varying degree of specificity in the representation required (e.g., MATCH trials and MISMATCH trials), then there should be an interaction between trace distinctiveness and the task's discrimination demand. We hypothesized that the HIGH DISTINCTIVENESS context should favor MISMATCH trials more than MATCH trials, whereas the LOW DISTINCTIVENESS context should favor MATCH trials more than MISMATCH trials.

In accordance with our hypothesis, the low visual distinctiveness between the characters in the LOW DISTINCTIVENESS context promoted a match between the test character and the participant's representation, thus facilitating MATCH rather than MISMATCH trials (Experiment 1 and 2a). Indeed, the MATCH trials required less discrimination than the MISMATCH trials, in which the participant had to simulate specific features in order to discriminate the simulated character from the test character (i.e., to find a mismatch). By contrast, the high distinctiveness of the characters in the HIGH DISTINCTIVENESS context promoted the simulation of the specific features of the characters and discrimination, and this favored MISMATCH rather than MATCH trials (Experiment 1 and 2a).

Furthermore, and in accordance with our hypothesis, by decreasing the specificity of this simulation, the DVN displayed at the time of the simulation of the character reduced the benefit of the (NEW)HIGH DISTINCTIVENESS context for MISMATCH trials (Experiments 2a and 2b). At the same time, and in accordance with the hypothesis of a simulation scale going from the more overlapping to the more specific features, the

decrease in the specificity of the simulation caused by the DVN was accompanied by an increased benefit of the (NEW)LOW DISTINCTIVENESS context for the MATCH trials, but only when the visual features of the characters did not already overlap sufficiently, as in Experiment 2b rather than in Experiment 2a. These results support the hypothesis that the interaction between distinctiveness and trial type is firmly underpinned by the specificity of the emerging representation. Indeed, a more specific emerging representation is more advantageous for establishing a MISMATCH than a MATCH.

One caveat would be that factors (i.e., executive or decisional factors) other than those manipulated here were involved in our task. Indeed, it is generally reported in the literature that such factors are involved in memory retrieval processes (for instance, see Koriat, 1993; Koriat et al., 2000). However, exploring this implication was not our aim.² We encourage the exploration of this implication in future studies

A second potential caveat might be that the DVN consumes attentional or executive resources rather than interfering with the simulation of specific trace features. However, this interpretation is unlikely as the main effect of DVN was not significant in any of the experiments. Moreover, our finding that DVN resulted in better performance in the NEWLOW DISTINCTIVENESS context for the MATCH trials (Experiment 2b) is inconsistent with the hypothesis of an attentional effect of DVN. In line with this view, previous studies have already reported that the DVN does not impact executive functioning or attentional resources (Dean et al., 2005; McConnell & Quinn, 2004; Sheldon et al., 2019). Despite this, DVN has been found to affect perceptual processes and mental imagery. For instance, DVN altered recall of words that had been memorized with a mental imagery instruction (the “pegword” technique; e.g., “1 is a gun that shoots apples.”) but did not impair recall of words that had been memorized with a subvocal repetition instruction (McConnell & Quinn, 2004; for disruption of encoding, see also Quinn & McConnell, 2006). Another study showed that DVN reduced the proportion of internal (specific) details produced during the description of an imagined scenario but did not affect the proportion of external (nonspecific) details

produced (Sheldon et al., 2019). Given that mental imagery and imagination are based on sensorimotor simulation (Barsalou, 2008, 2009), it has been proposed that the processing of a DVN by the perceptual systems interferes with simulation and reduces the specificity of the emerging representation (Purkart et al., 2019). Since, in our study, the HIGH DISTINCTIVENESS context provided the maximum amount of specific detail, it follows that DVN should be at its most detrimental when participants need to identify a mismatch in this context.

A third potential caveat comes from the image-definition hypothesis (Chubala et al., 2020), which states that a DVN only affects the representation of ill-defined images (e.g., snowflakes and textures) but not of well-defined images (e.g., apples). The more differences there are between images, the more well-defined the image representations will be (see p.3,³ Chubala et al., 2020). However, this alternative hypothesis cannot explain our results because DVN was only detrimental for characters in the HIGH DISTINCTIVENESS context (who had many different features). In addition, a beneficial effect of DVN was observed for characters in the LOW DISTINCTIVENESS context (who had the lowest number of different features). The discrepancy between the results of Chubala et al. (2020) and our own can be explained by methodological differences. Indeed, in our study, the DVN was not presented at the same time as the stimuli during the study and the test phase, but only during the simulation at the time of the test phase. In the light of this methodological discrepancy, other studies (e.g., Sheldon et al., 2019), in which the DVN was only presented during the formation of the representation in the test phase, suggest that a DVN reduces the specificity of the emerging representation rather than specifically affecting ill-defined representations of images. In this study, DVN only affected the production of internal (specific) details. According to the image-definition hypothesis, an internal-specific detail (e.g., “the dog was a white Great Dane with black spots”) corresponds to a well-defined image because it refers to a detailed representation of a specific dog instance. Therefore, the effect of DVN seems to differ depending on the moment of presentation. When presented during the test phase, it seems to reduce the specificity of the emerging representation by affecting the simulation of specific trace features. The results of Experiment 2b suggest that affecting the simulation of specific trace features by means of a DVN favors the simulation of overlapping trace features. Overall, these results suggest a simulation scale going from overlapping to specific trace features.

The hypothesis of a simulation scale going from overlapping to specific trace features is consistent with the act-in model (Versace et al., 2009; Versace et al., 2014). Act-in

² Based on the recommendations of an anonymous reviewer, a signal detection analysis was performed on d' (accuracy) and C criterion (bias). Results (available in the Supplementary Material) show decision criteria shift between the distinctiveness contexts in Experiments 1 and 2a but not 2b. But since the different conditions (trial type and distinctiveness context) were randomized, the participant had no information about the condition of the trial he/she was performing. As there is no intrinsic character distinctiveness during the test phase, a parsimonious interpretation would be that the character distinctiveness emerges from the overlap between the characters' features when the characters are presented in a block manner during the study phase. Consequently, it seems more likely that it is the difference in the trace discriminability that may lead to a shift in the decision criterion in our experiment (rather than a shift in the decision criterion alone and without relation to a memory process).

³ “One can easily compare photographs of two different apples by comparing the overall shape of the apple, the presence or absence of a stem, the shininess of the surface, and so on. In contrast, photographs of snowflakes, as with textures, have many minute differences which will be poorly represented in the image” (Chubala et al., 2020, p. 3).

is a multiple trace model which holds that all sensorimotor experiences are accumulated in the form of memory traces in our cognitive system. These traces reflect the brain states that are specific to each experience and involve the different sensorimotor features (or details). Representations would emerge along a continuum depending on the number of traces involved in the emergence and the dynamic activation (i.e., simulation) of trace features. The integration mechanism corresponds to the binding of the features of the current situation and permits the propagation of activation to specific features that are not already activated by the features of the current situation. This propagation, called intratrace activation, is facilitated by high trace distinctiveness and is beneficial when the discrimination demand of the task is high. This explains why a HIGH DISTINCTIVENESS context favored MISMATCH trials rather than MATCH trials in our study. This propagation to many specific features of the trace through intratrace activation limits the propagation to the features that overlap with a large number of traces and produces the emergence of a specific representation. The propagation to overlapping features is called intertrace activation. This is facilitated by low trace distinctiveness but is detrimental when the discrimination demand of the task is high. This explains why a LOW DISTINCTIVENESS context favored MATCH trials rather than MISMATCH trials in our study. On the one hand, strong intertrace propagation to overlapping features reduces intratrace activation, and this excludes specific features and contexts from the emerging representation, thus resulting in the emergence of a nonspecific representation. By contrast, strong intratrace propagation to many specific features limits intertrace activation as the probability of the memory system finding matching traces is reduced. Therefore, intertrace and intratrace activations are thought to be mutually detrimental. Thus, our results can be explained by a scale of activation going from intertrace (i.e., simulation of overlapping features) to intratrace propagation (i.e., simulation of specific features).

Taken together, the results of the present study suggest, in a specific (episodic) associative-recognition memory task, that emerging representations can be organized along a continuum of specificity based on the number of traces involved in the emergence of the representation. Future studies are needed to test our hypotheses at the other points of the continuum (e.g., in nonspecific/semantic tasks) in order to generalize this idea of a continuum of specificity. A growing number of studies support this idea of a continuum of specificity, which could improve our understanding of memory (Craig, 2002; Irish & Vatansver, 2020; Renoult et al., 2019; Renoult et al., 2016; Sheldon et al., 2020; Versace et al., 2009; Versace et al., 2014). Future studies should focus on the factors that influence the specificity of the emerging representation (i.e., where on the continuum the representation is located). Our data confirm that trace distinctiveness is one of these key factors (Brunel et al., 2013, 2010a) as it would facilitate the simulation of trace-specific features.

Appendix

Table 4 List of actions and objects used in the memory task (translated from French)

LIST A	LIST B
Sit on:	Play:
a chair	the violin
an armchair	the piano
a park bench	the guitar
a stool	the drums
Water:	Put:
a flowerpot	a robot toy
a tree	a dinosaur toy
a bush	a horse toy
a cactus	a cat toy
Utilize:	Cooking with:
a computer	a barbecue
a television	a gas cooker
a hi-fi system	a coffee machine
a jukebox	a microwave
Boarding:	Use:
a car	a shower
a bus	a bathtub
a motorbike	a sink
an airplane	a toilet
Lie down on:	Contemplate:
a bed	a statue
a sofa	an armor
a deckchair	a painting
a bench	a fountain
Pick up:	Do sports with:
a superhero toy	a treadmill
a dragon toy	a punching bag
a helicopter toy	a weight bench
a butterfly toy	a basketball

Table 5 Sensitivity analysis for Experiment 1, 2a, and 2b

Experiment	Correct responses (proportions from 0 to 1)	Response time (millisecond)
	Smallest effect sizes (Beta)	Smallest effect sizes (Beta)
Exp. 1	0.112*	−195*
Exp. 2a	0.130*	−320
Exp. 2b	0.109*	−64

Smallest detectable effect sizes (beta values) with 80% power for each of the experiments and dependent variables on the interaction of interest. Values obtained from the comparison of linear mixed models including the interaction of interest with a model including all other effects without the interaction of interest (see details of the procedure in the statistical analysis scripts [<https://osf.io/qghvx/>]). Values with a star correspond to the estimation of a Distinctiveness × Trial Type interaction effect, while those without a star correspond to a Distinctiveness × Trial Type × Interference interaction effect.

Table 6 Experiment 1 linear mixed-model output (CR)

Fixed effects						
	Est/Beta	SE	<i>t</i>	<i>p</i>	95% CI	
Intercept	0.810	0.025	31.927	<.001	0.76	0.86
Distinctiveness	−0.260	0.032	−8.257	<.001	−0.32	−0.2
Trial Type	−0.206	0.032	−6.546	<.001	−0.27	−0.14
Distinctiveness × Trial Type	0.312	0.045	6.996	<.001	0.22	0.4
Random effects						
	Variance	SD				
Participant (Intercept)	0.005	0.072				
Residual	0.212	0.460				

The *p* values for fixed effects calculated using Satterthwaites approximations

Model equation: CR ~ Distinctiveness * Trial Type + (1 | Participant)

REML criterion at convergence: 2239.6

Table 7 Experiment 1 linear mixed-model output (RT)

Fixed effects						
	Est/Beta	SE	<i>t</i>	<i>p</i>	95% CI	
Intercept	1,371.28	68.94	19.890	<.001	1,235.22	1,507.60
Distinctiveness	314.65	49.05	6.415	<.001	218.53	410.71
Trial Type	49.73	47.23	1.053	.293	−42.81	142.24
Distinctiveness × Trial Type	−208.90	69.77	−2.994	.003	−345.5	−72.11
Random effects						
	Variance	SD				
Participant (Intercept)	136,677	369.7				
Residual	318,810	564.6				

The *p* values for fixed effects calculated using Satterthwaites approximations

Model equation: RT ~ Distinctiveness * Trial Type + (1 | Participant)

REML criterion at convergence: 16942.7

Table 8 Experiment 2a linear mixed-model output (CR)

Fixed Effects						
	Est/Beta	SE	<i>t</i>	<i>p</i>	95% CI	
Intercept	0.760	0.035	21.737	<.001	0.692	0.829
Distinctiveness	−0.198	0.046	−4.300	<.001	−0.288	−0.108
Trial Type	−0.062	0.046	−1.358	.175	−0.153	0.028
Interference	0.016	0.046	0.340	.734	−0.074	0.106
Distinctiveness × Trial Type	0.260	0.065	4.001	<.001	0.133	0.388
Distinctiveness × Interference	−0.052	0.065	−0.800	.424	−0.18	0.075
Trial Type × Interference	−0.026	0.065	−0.400	.689	−0.153	0.101
Distinctiveness × Trial Type × Interference	0.026	0.092	0.283	.777	−0.154	0.206
Random effects						
	Variance	SD				
Participant (Intercept)	0.00527	0.07259				
Residual	0.20334	0.45093				

The *p* values for fixed effects calculated using Satterthwaites approximations.

Model equation: CR ~ Distinctiveness * Trial Type * Interference + (1 | Participant)

REML criterion at convergence: 1969.5.

Table 9 Experiment 2a linear mixed model output (RT)

Fixed effects						
	Est/Beta	SE	<i>t</i>	<i>p</i>	95% CI	
Intercept	1,279.627	85.856	14.904	<.001	1,110.35	1,448.775
Distinctiveness	133.576	66.710	2.002	.045	3.133	263.963
Trial Type	-6.353	62.576	-0.102	.920	-128.718	115.95
Interference	-149.847	60.977	-2.457	.014	-269.056	-30.642
Distinctiveness × Trial Type	-24.563	91.186	-0.269	.788	-202.772	153.760
Distinctiveness × Interference	203.432	94.871	2.144	.032	18.009	388.948
Trial Type × Interference	179.700	88.306	2.035	.042	7.033	352.302
Distinctiveness × Trial Type × Interference	-309.719	129.783	-2.386	.017	-563.476	-56.035
Random effects						
	Variance	SD				
Participant (Intercept)	175,325	418.7				
Residual	262,879	512.7				

The *p* values for fixed effects calculated using Satterthwaites approximations.

Model equation: RT ~ Distinctiveness * Trial Type * Interference + (1 | Participant)

REML criterion at convergence: 15773.8.

Table 10 Experiment 2b linear mixed model output (CR)

Fixed effects						
	Est/Beta	SE	<i>t</i>	<i>p</i>	95% CI	
Intercept	0.721	0.024	29.861	<.001	0.673	0.768
Distinctiveness	0.113	0.029	3.918	<.001	0.056	0.170
Trial Type	0.019	0.029	0.653	.514	-0.037	0.075
Distinctiveness × Trial Type	-0.115	0.041	-2.828	<.01	-0.195	-0.035
Random effects						
	Variance	SD				
Participant (Intercept)	0.006056	0.07782				
Residual	0.176154	0.41971				

The *p* values for fixed effects calculated using Satterthwaites approximations.

Model equation: CR ~ Distinctiveness * Trial Type + (1 | Participant)

REML criterion at convergence: 1930.5.

Table 11 Experiment 2b linear mixed-model output (RT)

Fixed effects						
	Est/Beta	SE	<i>t</i>	<i>p</i>	95% CI	
Intercept	1,293.95	74.87	17.283	<.001	1,146.56	441.315
Distinctiveness	-53.20	53.83	-0.988	.323	-158.514	52.042
Trial Type	-105.42	55.73	-1.892	.059	-214.48	3.518
Interference	-11.95	55.88	-0.214	.831	-121.320	97.276
Distinctiveness × Trial Type	154.82	77.38	2.001	.046	3.548	306.230
Distinctiveness × Interference	-106.02	76.21	-1.391	.165	-255.027	43.098
Trial Type × Interference	124.82	78.36	1.593	.111	-28.348	278.221
Distinctiveness × Trial Type × Interference	-87.23	108.91	-0.801	.423	-300.383	125.661
Random Effects						
	Variance	SD				
Participant (Intercept)	146151	382.3				
Residual	229960	479.5				

The *p* values for fixed effects calculated using Satterthwaites approximations.

Model equation: RT ~ Distinctiveness * Trial Type * Interference + (1 | Participant)

REML criterion at convergence: 19114.

Table 12 Experiment 2b linear mixed-model output (CR)

Fixed effects						
	Est/Beta	SE	<i>t</i>	<i>p</i>	95% CI	
Intercept	7.230e-01	3.157e-02	22.899	<.001	0.661	0.785
Distinctiveness	9.859e-02	4.070e-02	2.423	.015	0.019	0.178
Trial Type	−4.695e-03	4.070e-02	−0.115	.908	−0.084	0.075
Interference	−4.695e-03	4.070e-02	−0.115	.908	−0.084	0.074
Distinctiveness × Trial Type	−9.390e-02	5.755e-02	−1.632	.103	−0.206	0.019
Distinctiveness × Interference	2.817e-02	5.755e-02	0.489	.625	−0.084	0.141
Trial Type × Interference	4.695e-02	5.755e-02	0.816	.415	−0.066	0.16
Distinctiveness × Trial Type × Interference	−4.225e-02	8.139e-02	−0.519	.604	−0.201	0.117
Random effects						
	Variance	SD				
Participant (Intercept)	0.006051	0.07779				
Residual	0.176376	0.41997				

The *p* values for fixed effects calculated using Satterthwaites approximations.

Model equation: CR ~ Distinctiveness * Trial Type * Interference + (1 | Participant)

REML criterion at convergence: 1946.8.

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Declarations

Conflicting interests The Author(s) declare(s) that there is no conflict of interest.

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- The data and statistical analysis scripts for all experiments are available online (<https://osf.io/qghvx/>). None of the materials for the experiments reported here is available, and none of the experiments was preregistered.

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