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Structuring process and closure principle in spatial and temporal reproduction tasks.

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Running Head: Structuring process and closure principle

Abstract

The goal of the experiment reported was to replicate the previous Sarrazin's (2000) study in order to verify, with an adequate methodological procedure, whether or not the closure principle applied in spatial and temporal reproduction tasks. The hypothesis defended was that the closure of the pattern is an intrinsic property of the structuring process in spatial memory. The stimuli consisted of eight visually presented dots that appeared sequentially with inter-dot distances corresponding to inter-dot durations. After a learning phase, participants reproduced the spatial (space condition) or temporal (time condition) characteristics of the target 60 times in succession. We analyzed the variance level for both element location and Inter-Element-Interval (IEI) on spatial and temporal responses. Two main results emerge from this experiment: (1) the critical dependency of the closure principle to the nature (spatial or temporal) of the response, (2) the importance to consider both locations and intervals as complementary information. These results are discussed in the light of physical system, in particular in term of compensation phenomenon and we proposed a mathematical model that replicates the qualitative feature of variance for both space and time conditions.

Introduction

Many earlier studies on perception, memory, and motor processes led their authors (Bartlett, 1932; Burnham, 1903; De Camp, 1915; Gibson, 1929; Hebb, 1949; Köhler, 1947; Lashley, 1950; Loeb, 1901) to consider intra-individual response variability as a meaningful characteristic of the functioning of the system. However, until the recent advent of dynamical approaches (cf. Van Geert, 1998), contemporary psychology has shown relatively little interest in intra-individual variability. While developments in neurosciences, and in motor control in particular, brought variability back to the centre of the stage, acknowledging that it was inherent in every biologic system (Collins & DeLuca, 1993; Newell and Corcos, 1993; Schöner & Kelso, 1988; Webber & Zbilut, 1994), main stream cognitive psychology, including the field of memory, has continued to focus on patterns of accuracy as primary indicators of the mode of functioning of the system (see Finke & Shepard, 1986, for a review).

Re-establishing the link with the early studies cited above, and separately analyzing both the time course of accuracy (difference between the required pattern and the produced pattern on each trial) and variability (difference between subsequent reproductions independently of the required pattern), Giraudo and Pailhous (1999) sought to identify the role and meaning of variability in image formation and stabilization in memory. Their results demonstrated that these two aspects of information processing evolve under different dynamics. They referred to the first dynamics as a migration process (i.e., evolution towards the required pattern); this process being captured by the accuracy time course, defines the maximum level of accuracy reached when accuracy no longer improves over several trials. They referred to the second dynamics as a structuring process (i.e., evolution of response consistency); this process being captured by the variability time course (defined as the difference between successive responses independently of the target configuration), defines

the maximum level of image resolution when variability reaches a steady state. These results raise the question of the mechanisms that underlie this structuring process, and consequently the stabilization of the memory configuration.

These results have some similarities with studies carried out in the domain of neural modelling, and in particular about the question of emergent properties of network interactions (e.g., Carpenter and Grossberg, 2003; Grossberg, 1987). In their Adaptative Resonance Theory (ART), these authors evoke that a key issue leading to network models concerns how the behaviour of individuals adapts successfully in real-time to constraints imposed by their environments. In order to analyse this issue, the authors identify the functional level on which an individual's behavioural success is defined and assume that a key behavioural properties are often emergent properties due to interactions among many cells in a neural network. Often, network emergent properties are much more complex than the network components from which they arise. In a network model, the whole is far greater than the sum of its parts. In addition the formal relationships among those emergent properties may be quite subtle, and may reflect the delicate interplay of behavioural properties that are characteristics of living organisms. Thus, in the context of structuring process of visual configuration in memory, network models can excite our interest by showing us how subtle and complex functional properties can emerge from interactions among simple components.

Using spatio-temporal target configurations consisting of 8 dots appearing one after the other on a horizontal line, Sarrazin (2000) studied the properties of stabilized information. Analyzing the variability of successive reproductions, Sarrazin (2000) found that, (1) when the pattern stabilized, individual elements varied in a coordinated fashion indicating the existence of an overarching synergy, (2) the variance of location for the outermost elements (about 0.2 cm) is smaller than the variance of location for other elements (until 1.2 cm), and (3) this last result is observed from the first trials on. As the variance measure expressed the

stability level of dots location independently of the accuracy of that location, these results suggested that the structuring process involves a fixation of the boarder elements in view to close the memorized pattern, thus constituting a form. This reminds the closure principle defended by Gestalt psychologists in the first half of the last century (e.g., Köhler, 1947, Koffka, 1935).

Wertheimer (1923) initially introduced the concept of closure in a study on the principles of perceptual organization. Specifically, the principle of closure refers to the tendency towards a greater perceptual stability possessed by closed areas as compared with enclosed ones, and hence to the tendency for closed areas to be more readily attained and maintained in perception (Luchins & Luchins, 1959). In two studies performed in the first half of the last century, Tiernan (1938) and Gibson (1929) have shown that when participants were presented with geometric figures, there is a marked tendency to recall or reproduce non closed figures as closed ones, that is, to modify the perceived form from memory. Moreover, different studies have provided some evidence that closure is important in contour detection (Braun, 1999; Elder & Zucker, 1993; Kovacs & Julesz, 1993; Pettet, McKee, & Grzywacz, 1998) and that the brain perceives boundaries to enclose an object (Koshman, 2006), This neural phenomenon of boundaries perception has been highlighted by Grossberg and Mingolla (1985) with the notion of boundaries contour system (BC system). The properties of the BC system provide a unified explanation of several ostensibly Gestalt rules (completion, segmentation, grouping) and computer simulations, based on a hierarchy of orientationally tuned interactions, established the formal competence of the BC system as a perceptual grouping system.

However, generally, the stimuli used allowed the participants to have a simultaneous perception of the pattern whereas in Sarrazin's (2000) study the stimuli were sequentially presented. Even if Gibson (1966) has emphasized that a series of items can be presented in adjacent order or in successive order, in both cases the apprehension is equivalent, it is possible that closure principle do not apply for sequentially presented pattern, in such a way that the result previously obtained was due to an experimental bias. Indeed, in Sarrazin's study (2000) participants recalled the spatial or the temporal pattern of a space-time target configuration projected on a computer screen. In such a situation, the edges of the screen being always visible, it is possible that the participant have used the edges as external cues (i.e., as reference) to learn very soon an almost absolute starting and ending position.

Thus, the first goal of this experiment will be to replicate Sarrazin's (2000) study using the same paradigm (see also Sarrazin, Giraudo, Pailhous, & Bootsma, 2004). However, we modified their procedure by introducing a space-time target configuration projected on a wall (i.e., a situation in which the reproduction space is not limited by the boundaries of a computer screen). In other words, this raised the following issue:

If the closure of the pattern is an intrinsic property of the structuring process, and thus the way the participant used to better memorize and reproduce this pattern, a similar distribution of the variance over elements as in Sarrazin's previous experiment (2000) will be found in the present experiment since the positions of the outermost elements have to be fixed. On the contrary, if the closure of the pattern is due to an experimental bias, and thus is not an intrinsic property of the structuring process, then the distribution of the variance over elements will be relatively flat because each element will approximately have the same variance level.

A second question deals with the dependent character of the closure principle on the nature (spatial or temporal) of the response. Some authors, like Anderson (1974) and Collyer

(1977), suggested that the organization of information is identical whatever the nature of the reproduction, a spatial or temporal one. Following this argument, Jones and Huang (1982) developed an algebraic model to account for space-time contaminations in their psychological data characterized by a symmetrical effect of the spatio-temporal incongruence on a spatial or a temporal judgment task. Thus, in the context of the closure principle, and considering the symmetrical space-time balancing in spatial or temporal reproductions, the question which is to be examined is whether there is a temporal closure principle comparable to the spatial closure principle.

Finally, a simple mass-spring model is proposed to account for the observed distribution of the variance.

Method

Participants:

Twelve adult volunteers (6 women and 6 men) participated in this experiment. Their mean age was 23 (range = 20 - 27 years). Participants were divided in two groups. The first group was asked to reproduce the spatial characteristics of the target configuration (space condition) while the second group had to reproduce the temporal characteristics (time condition).

Insert Figure 1 about here

Material:

The stimuli consisted of eight white dots (1 cm in diameter) presented against a black background in a dark testing booth. Dots appeared, one at the time, on a black wall (width:

4m - height: 3m) located 3.m from the participant. Each dot was visible for 26 ms at a position along the horizontal axis from left to right, so that the eight dots formed a uni-dimensional spatial configuration (see Figure 1).

Insert Table 1 about here

The overall configuration covered 60 cm and was projected in the centre of the wall with a virtual start point located at an arbitrary zero position and a virtual end point located at an arbitrary 60 position. The sequence (of eight successive dots) lasted 6s. The configuration was characterized by variable but proportional spatial and temporal inter-dot intervals (IDI). Three of the spatial IDIs corresponded to 3.73 cm covered in 373 ms, two were about half as long (i.e., 1.9 cm, covered in 190 cm), and two were about 1.5 times as long (i.e., 5.5 cm covered in 550 ms). The seven spatial IDIs were thus always covered at a constant speed (10 cm s^{-1}). Finally, the spatial and temporal distribution of the eights dots were defined considering two criteria: (1) the outermost dots were approximately positioned at an equivalent distance from the virtual start and end location, (2) The three different spatial and temporal IDIs were in the vicinity one from other in such a way that a short interval, for instance, was at the same time near a medium and a large interval (see table 1).

In the “space condition”, participants were asked to reproduce the spatial pattern of the target configuration whereas in the “time condition”, participants had to reproduce the temporal pattern of the target configuration. The same space-time target configuration was introduced in both spatial and temporal conditions

Stimulus presentation and response recording were controlled by a dedicated application developed under the Labview™ 5.1 program in which the measurement accuracy was about 1/100 cm. In time condition, participants’ responses were obtained with a

pushbutton connected to the computer's parallel port via a cable insulated from electromagnetic disturbances. Its ergonomic features and reliability (button sensitivity, lack of rebound of the signal provided by the switch, efficient anatomical position of the participant's hand) were designed to avoid all interference effects (minimal noise in the signal).

Procedure:

There were three phases in each experimental condition: a familiarization phase, a learning phase and a reproduction phase.

- Familiarization phase: In the familiarization phase participants acquainted themselves with the experimental apparatus, learning how to handle the mouse to locate the dots (in the space condition) or to use the pushbutton to reproduce the rhythm (in the time condition) of the target configuration.

- Learning phase: The participants' spatial task was to memorize each dot's location (i.e., the spatial configuration), whereas the participants' temporal task was to memorize the rhythm of dots appearance. In order to avoid all possible parasitic effects stemming from motor involvement, the participants did not reproduce the sequence during the learning phase. **T**his phase consisted of 20 successive presentations of the same space-time sequence. Two consecutive sequences were separated by a 1.5 sec. time interval. Consequently, the learning phase lasted 150 seconds.

- Reproduction phase. At the end of the learning phase, the target configuration disappeared and the participant's task was to reproduce the learned pattern (spatial or temporal) from memory as precisely as possible. In the space condition, the participant had to locate each of the eight dots on the wall using the mouse. In order to minimize the movements with the mouse and thus being in a situation similar to a classic use of the mouse (using a computer screen), we increased the gain of the mouse. No vertical precision was required with dots being automatically projected on the horizontal axis in the middle of the wall. In the time

condition, the participant had to reproduce the rhythm of dots' appearance (i.e., the temporal pattern of the target configuration) using the pushbutton sampled at a frequency of 1000Hz. Sixty trials were performed, without re-examination of the target. For each trial a start beep indicated to the participant the beginning of the reproduction. At the end of the sequence, an end beep occurred 340 ms after the participant's eight push to allow the participant to answer according to his or her own temporal scale. At the end of each reproduction, the next trial began in an automatic way 1.5 s later (as in the learning phase). The experiment took approximately one hour in the space condition, and approximately thirty minutes in the time condition.

Data analysis:

We computed the variance of position for each element's configuration, and the variance of each inter element interval (IEI) in both spatial and temporal reproductions. Because in a previous study Berberian (2003) showed a stabilization phase of each dot location during the ten first trials, we decided to compute these two measures separately, that is, on the ten first trials, on one hand, on the fifty last trials, on the other, and to compare the two blocks of trials. The significance level (p) for the ANOVA statistical analysis (expressed by the Fisher's F) was set at 0.05.

Results

1. Analysis of the element variance.

The mean level of variance for dots was 1.59 cm (S.D. = 1.09 cm) in the space condition, and 24 ms (S.D. = 6 ms) in the time condition. The evolution of this level of variance has been analyzed by comparing the mean level of variance for the ten first trials with the mean level of variance for the fifty last trials in both space and time conditions. This analysis revealed a main effect of blocks of trials in both space [$F(1,7) = 22.43$; $p < .05$] and

time [$F(1,7) = 9.22$; $p < .05$] conditions. In both conditions, this effect was due to a decrease of the mean level of variance during the ten first trials (see figure 2).

Insert Figure 2 about here

In order to shed light on how the information is organized in memory, we analyzed the level of variance of each element. As shown in Figure 3, the level of variance of each element directly depends on (1) their location in the reproduction, (2) the blocks of trials (i.e., ten first trials versus fifty last trials), and (3) the nature of the response (spatial or temporal).

Indeed, in space condition (see Figure 3A), the analysis revealed a main effect of the elements' spatial location on the level of variance both in the ten first trials [$F(7,35) = 3.88$; $p < .05$] and the last fifty trials [$F(7,35) = 4.84$; $p < .05$]. Post-hoc analysis revealed that the level of variance was larger for the elements located at the centre of the spatial configuration (elements 4 and 5) than for the outermost elements (elements 1 and 8) in the two blocks of trials. The distribution of the elements' variance was well fitted by binomial tendency curves, characterized by a like-Gaussian profile, with coefficients of determination $R^2 = 0.9$ for the block of the ten first trials and $R^2 = 0.8$ for the block of the fifty last trials.

Concerning the time condition (see Figure 3B), the analysis revealed a non significant main effect of the elements' temporal location on the level of variance for the ten first trials [$F(7,35) = 0.42$, *ns*]. In other words, no specific organization appears during the ten first trials. In contrast, the analysis revealed a main effect of the elements' temporal location on the level of variance for the fifty last trials [$F(7,35) = 41.28$; $p < .05$]. The post-hoc analysis for the block of the last fifty trials revealed a linear increase of the level of variance from element 1 to element 8. Indeed, the repartition of the level of variance of each element's temporal location was well fitted by a linear trend line, characterized by a positive slope and a

coefficient of determination $R^2 = 0.98$. At first sight, it seems that the linearly increasing variance in temporal location is the result of a phenomenon of accumulating variance.

Insert Figure 3 about here

2. *Analysis of IEIs variance.*

The mean level of variance of the IEIs was 1 cm (S.D. = 0.24 cm) in the space condition and 7.7 ms (S.D. = 3.2 ms) in the time condition. The evolution of this level of variance was analyzed by comparing the block of the ten first trials with the block of the fifty last trials in both space and time conditions. This analysis revealed two mean results. Firstly, we observed a main effect of the blocks of trials in the space condition [$F(1,6) = 13.89$; $p < .05$] as well as in the time condition [$F(1,6) = 10.23$; $p < .05$]. Post hoc analysis revealed that this effect was due to a decrease of the level of variance between the block of the ten first trials and the block of the last fifty trials (see figure 4), in both space and time conditions. Secondly, we observed a larger level of variance for the elements than for the IEIs whatever the considered block of trials and whatever the nature (spatial or temporal) of the response are (in the space condition, $t(11) = 3.19$, $p<.05$ for the ten first trials, and $t(11) = 2.28$, $p<.05$ for the fifty last trials ; in the time condition, $t(11) = 4.76$, $p<.05$ for the ten first trials, and $t(11) = 6.38$, $p<.05$ for the fifty last trials).

Insert Figure 4 about here

However, the comparison of the level of variance of each IEI, did not reveal an effect neither for the block of the ten first trials [$F(6,30) = 2.13$, n.s] nor for the block of the fifty last

trials [F(6,30) = 2.14, n.s] in the space condition (see Figure 5A). Concerning the time condition (see Figure 5B), the level of variance of each IEI did not differ from each other in the last fifty trials [F(6,30) = 1.25, n.s]. In contrast, we observed different levels of variance for the IEIs in the ten first trials [F(6,30) = 3.27, p<.05].

Thus, compensation of variance between elements occurs in the space condition as well as in the time condition and set up (in time condition) on the ten first trials.

Insert Figure 5 about here

3. A dynamical system approach.

Previous modelling studies on reproduced extents in recall tasks use static models where the issue of the dynamical changes, i.e. intra-individual response variability across trials, is not addressed. We give here some steps towards a dynamical approach for the modelling of the reproduced spatial and temporal extents. Let us denote $x_i(t)$ the spatial (or temporal) location of the ith dot at trial t. In the space condition, $x_i(t)$ stands for space position, and in the time condition $x_i(t)$ is a time location. We have $i \in \{1,n\}$ (in the present Experiment $n = 8$) and for convenience we consider trials as a continuous time. A simple way to model interaction between dots is to consider the n-dots configuration as a system of mass driven by an interacting force. Evolution of the system follows:

$$m\frac{d^2x_i(t)}{dt^2} = F(x_{i+1}(t) - x_i(t)) - F(x_i(t) - x_{i-1}(t))$$

where m is a mass, F is a coupling function that models the interaction between two successive dots. For simplicity we consider a simple linear coupling function $F(x) = \alpha(x - \theta)$ where α is a parameter that describes the coupling strength and θ is the resting value at which the interacting function vanishes. (hereafter, we take the dimensionless value $\theta = 1$)

Therefore in our approach the evolution of the configuration is like an ideal mass-spring system. The system is fully described setting the initial conditions and the boundary conditions. For the initial conditions we take $x_i(0)$ as a uniform distribution on $[0,n+1]$ $x_i(0)=i$, and we consider an initial perturbation taking $dx_i(0)/dt$ as a random variable (normally distributed with mean 0 and standard deviation 0.25). We explore the closure hypothesis using two different boundary conditions. In the first numerical experiment we take $x_0(t)=0$ and $x_{n+1}(t)=n+1$, i.e. the boarder elements are fixed. In the second case, we still consider a fixed boundary at the origin ($x_0(t)=0$) but the last dot is free. Evolution of dot n is given by:

$$m\frac{d^2x_n(t)}{dt^2}=-F(x_n(t)-x_{n-1}(t))$$

i.e. there is no link to a fixed boundary. We focus our analysis on the variance produced by the dynamical system in both scenarii for each element. A typical result is shown in figure 6 for both scenarii.

Insert figure 6 about here

Discussion

The goal of the experiment reported was to replicate the previous Sarrazin's (2000) study in order to verify, with an adequate methodological procedure, whether or not the closure principle of a memorized pattern in spatial and temporal reproduction tasks could applied. Two main results emerge from this experiment. The first relates to the critical dependency of the closure principle on the nature (spatial or temporal) of the response. The

second concerns the importance to consider both locations and intervals as complementary information. Moreover we developed a mathematical model which captures some features of the experimental results.

1. The dependency of the closure principle to the nature of the response.

Studying the question of the mechanisms that underlie the structuring process of information in memory in spatial and temporal recall tasks, we demonstrated the existence of a distribution of elements' variance which was different according to the spatial or temporal nature of the response. Specifically, removing the experimental bias that could be induced by the edges of the computer screen in the Sarrazin's study (2000), we found that in the spatial task the outermost elements have smaller variance than the others, whereas in the temporal task the variance increased from the first to the last element.

The distribution of variances observed could derive from the form of the dots distribution since dots location (and thus intervals) was not completely distributed at random. However, it is difficult to understand why such an effect can occur regarding the distributed variance of dots and not regarding the distributed variance of IEIs. Moreover, as the spatial and temporal distributions are the same, it is also difficult to understand why different results appeared. In this context, we assume that the distribution of the eight dots have no influence on the variances observed.

As the space condition lasted approximately one hour while the time condition lasted approximately 30 minutes, it could be argued in first approximation that the differences in the experimental results could be ascribed to the possibility that a simple phenomenon of neural dynamics occurs, that is, how the brain responds to time. However, if we observe differences in the results, especially regarding dots location and evolution of IEIs variance between conditions, we also observe similarities which are difficult to explain by appealing to

differences in the way the brain responds to time. Consequently, the difference in time between the two conditions did not appear as a convincing argument to explain our results.

It could be argued that our result corresponded with the well known primacy and recency effects. However, it is difficult to understand why such effects appeared for spatial responses and not for temporal responses.

Our results could be understood in a simple way, by considering that the participants learned the absolute starting and ending positions across trials. If this consideration can partially explain the results of the spatial responses, it can not explain (1) that the variance level of the outermost element is low since the beginning of the reproduction, (2) why there is a different result for spatial and temporal responses, (3) how the absolute positions have been learned without external cues used as reference, and (4) why the location variance increased until the element situated at the half of the pattern, and decreased after, until the last element.

If participants clearly reproduce almost absolute starting and ending positions it is not because they learned it, but rather because they mentally structured the pattern by fixing the position of the outermost elements, coordinating the other in an overarching synergy. As the variance level of element location expressed the stability of the positions, we have to consider that for the spatial responses, fixed locations of the outermost elements, probably via a rapid, preattentive and automatic process (Grossberg & Mingolla, 1885), allowed to close the pattern and thus to constitute a form.

Luchins and Luchins (1959) argued that closed areas are more readily attained and maintained in perception. We assumed that a similar phenomenon occurred in spatial reproduction tasks as previously demonstrated by Tiernan (1938) or Gibson (1929). Moreover, our results showed that even if the elements are presented sequentially, the elaborated spatial representation ended to a closed configuration, that is, a configuration which constituted a whole entity. Some authors (Tversky, Geisler, & Perry, 2004) have

considered that this closure effect resulted both from good continuation – elements that continue a pattern tend to gather together–and proximity – items placed near from each other appeared to be part of a group – so that viewers mentally organized closer elements into a coherent group. However, the configuration used in the present experiment does not totally keep the principles of good continuation and proximity since the elements are presented sequentially with different spatial intervals (small, medium or large). As a result, the closure principle appeared as a basic property of element organization in spatial reproduction task. Moreover we observed that a Gaussian-like curve well fits the repartition of the variance over the spatial locations. This distribution of elements' variance revealed a phenomenon of compensation between elements that can be explained as a mass-spring model. In a mass-spring model which oscillated, the element variance level evolves as a function of the element distance to the boundaries. Our explanation found a large confirmation with the first scenario of the simple mass-spring model we develop since the distribution of the variance is similar to the Gaussain profile of the observed results for the spatial task.

In the time condition, no closure principle appears. However we have to remember that if space is always a closed area, time is always an open dimension. Our results showed that the distribution of the element temporal variance follows an increasing linear trend line. This linear increase indicated a phenomenon of variance accumulating over elements. This linear trend could thus be understood as a mass-spring model characterized by a single boundary, that is, only with a starting point. Here again, the second scenario replicates the linear increase of the level of variance obtained in the temporal task.

The analysis of the IEIs variance produced by the model reveals a compensation phenomena similar to the one observed in the experiment (simulations not shown). The variability observed in the recall experiments is qualitatively reproduced by a simple mass-spring model where all the elements have the same physical properties. A difference in the

boundary condition for the last element accounts for the difference in the variance distribution obtained in the spatial and the temporal task. This suggests that (i) the structuring process is governed by some simple laws and (ii) the closure principle is a key mechanism for spatial reproduction tasks.

2. Considering locations and intervals as complementary information.

Focusing our attention, on the IEIs variance level, we found that the variance of the intervals in the block of the last fifty trials was uniform both in space and time conditions. If this result confirms the observed phenomenon of compensation at work for the spatial locations, it brings an important issue on the interpretation of the element variance repartition for the temporal locations. Indeed, this result shows clearly that the phenomenon of accumulating variance, observed for the temporal elements did not prevent a uniform repartition of variance over the temporal intervals. However, this homogeneous repartition has progressively developed since the variance of intervals is statistically different for the first ten trials. Thus, we assumed that a compensation of variance occurs in the structuring process both for a spatial and a temporal memorized pattern even if this compensation operated in different ways. In the spatial recall task, the compensation process operated both at the level of elements and IEIs. We can affirm that this compensation process critically depends on the closure principle. In the temporal recall task, the compensation process only operated at the level of IEIs. In the same way, we assume that the lack of closure modifies the repartition of variance and thus necessitated time for a classical propagation phenomenon to occur.

Nevertheless, as the action system to drive pointing movements, (Van Wieringen & Beek, 1997), these results obviously show that locations and intervals are two complementary elements of information that allow to understand the implications of the structuring process of information in memory in a better way. Studying pattern reproduction in spatial and temporal

reproduction tasks, we demonstrated that the central nervous system used different ways according to the task constraints to end up at a same structuring process of information in memory. Indeed, the relationship between the emergent functional properties that govern the behavioural success and the mechanisms that generate these properties is far from obvious. A single network module may generate qualitatively different functional properties when parameters are changed. Conversely, two mechanisms which are mechanistically different may generate formally homologous functional properties (Grossberg, 1987). If the distribution of locations' variance differs according to the spatial or temporal nature of the response, the organization of information in memory leads to a phenomenon of variance compensation in both spatial and temporal reproductions. The cognitive and learning mechanisms which enable us to group, or chunk, ever more complex information into phenomenally simple unitized representations act to hide us the myriad of interactions underlying these representations during every moment of experience.

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Figure captions

Figure 1: Spatial position occupied by each dot in the target configuration over time characterized by variable distances between dots.

Figure 2: Mean element variance level for the ten first trials and the fifty last trials in both space (A) and time (B) conditions.

Figure 3: Variance distribution of each element for the ten first trials and the fifty last trials in both space (A) and time (B) conditions.

Figure 4: Mean interval variance level for the ten first trials and the fifty last trials in both space (A) and time (B) conditions.

Figure 5: Variance distribution of each interval in function of its location for the ten first trials and the fifty last trials in both space (A) and time (B) conditions.

Figure 6: Variance distribution of each element given by the model of (A) the space condition and (B) the time condition. Parameter is $\alpha/m = 1$ and we simulate over an arbitrary period of $T = 180$.

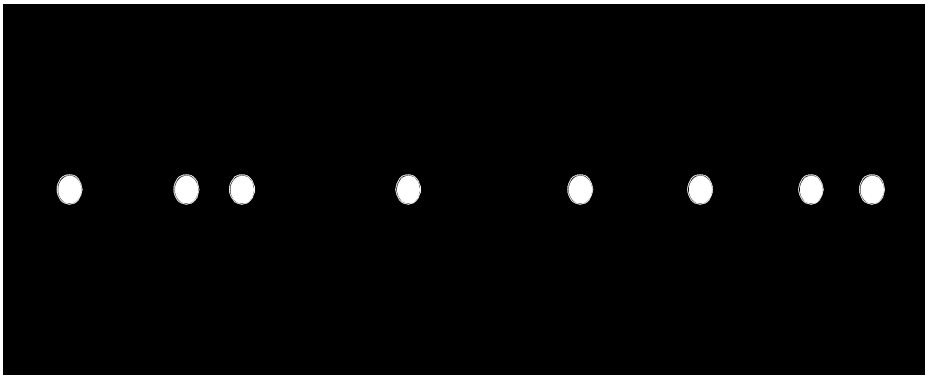

Figure 1

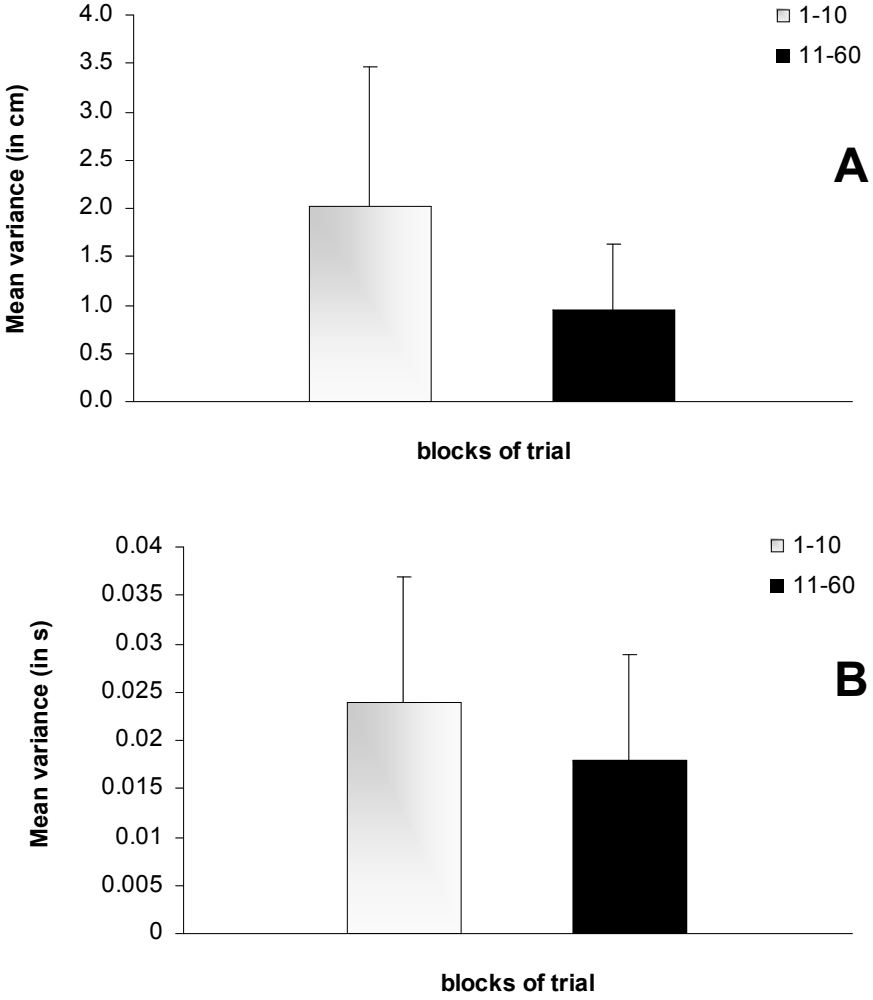
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Mean variance (in cm)
1-10
11-60
A
blocks of trial
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Mean variance (in s)
1-10
11-60
B
blocks of trial

Figure 2

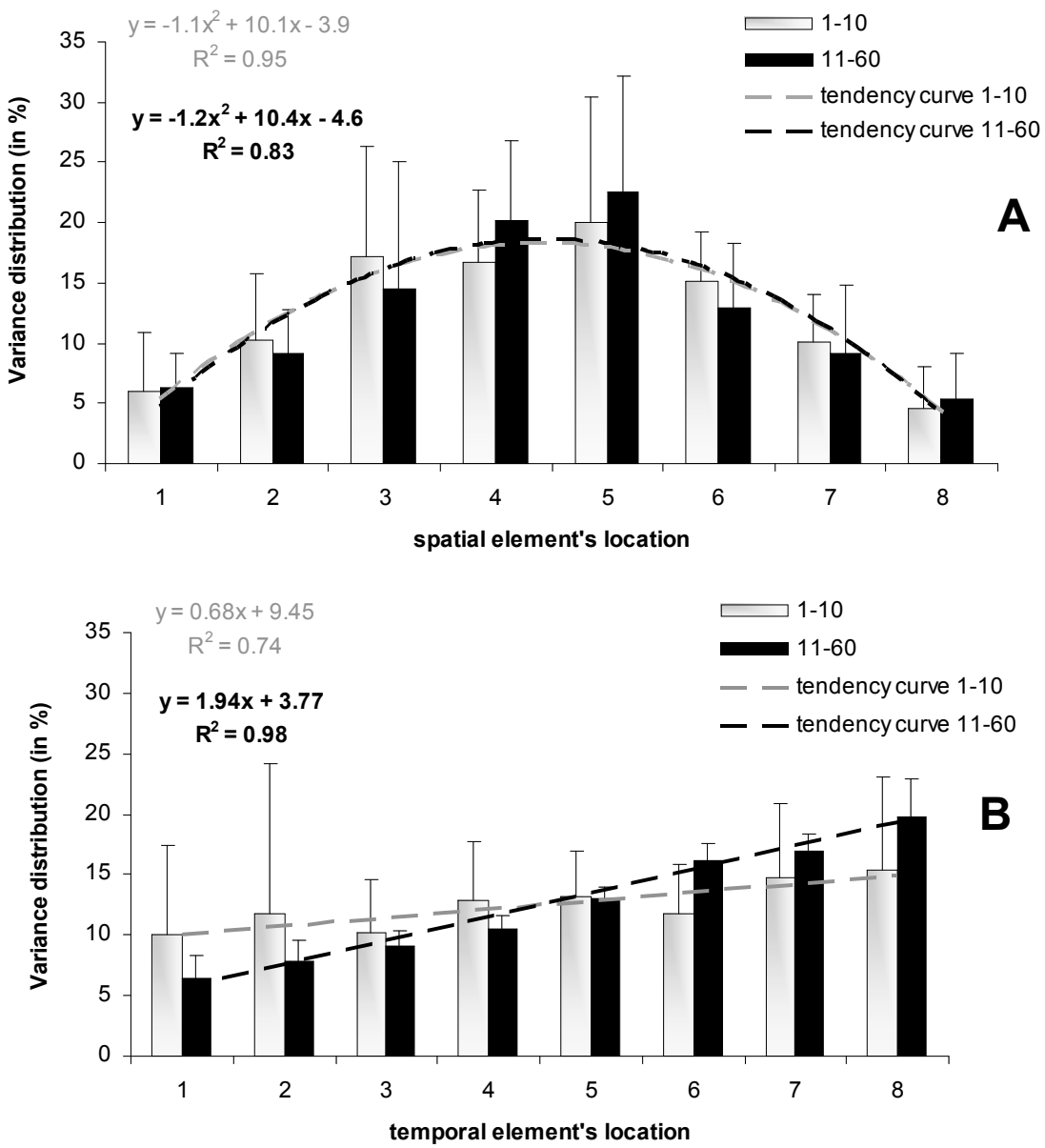
y = -1.1x2 + 10.1x - 3.9
R2 = 0.95
y = -1.2x2 + 10.4x - 4.6
R2 = 0.83
1-10
11-60
tendency curve 1-10
tendency curve 11-60
A
Variance distribution (in %)
spatial element's location
y = 0.68x + 9.45
R2 = 0.74
y = 1.94x + 3.77
R2 = 0.98
B
temporal element's location

Figure 3

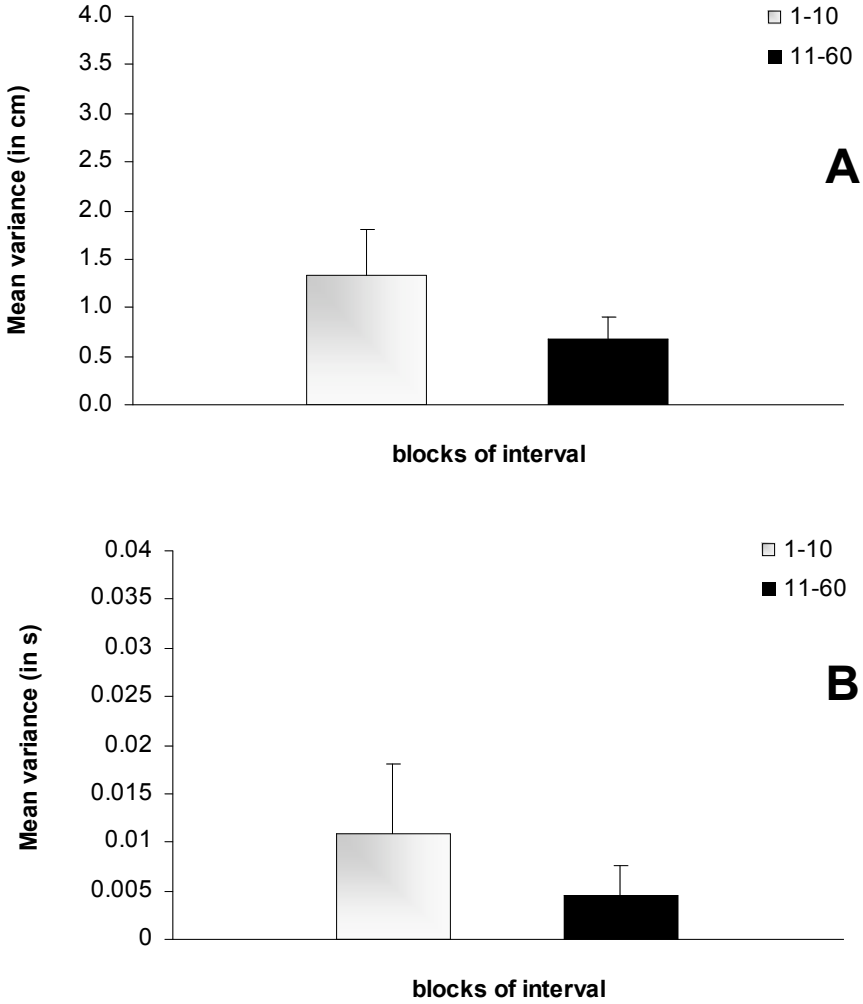
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Mean variance (in cm)
1-10
11-60
A
blocks of interval
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Mean variance (in s)
1-10
11-60
B
blocks of interval

Figure 4

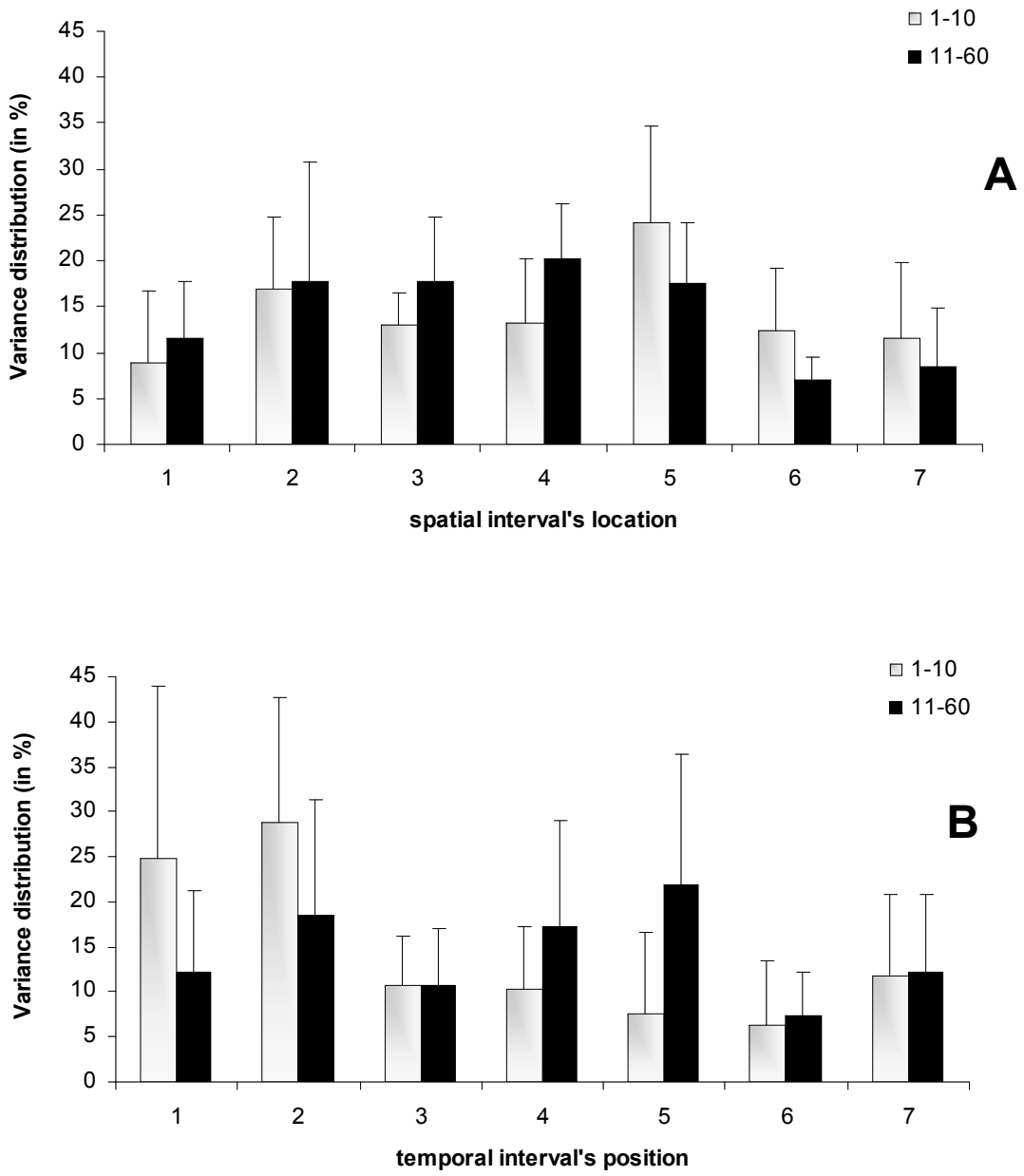
1-10
11-60
A
Variance distribution (in %)
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
spatial interval's location
1-10
11-60
B
Variance distribution (in %)
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
temporal interval's position

Figure 5

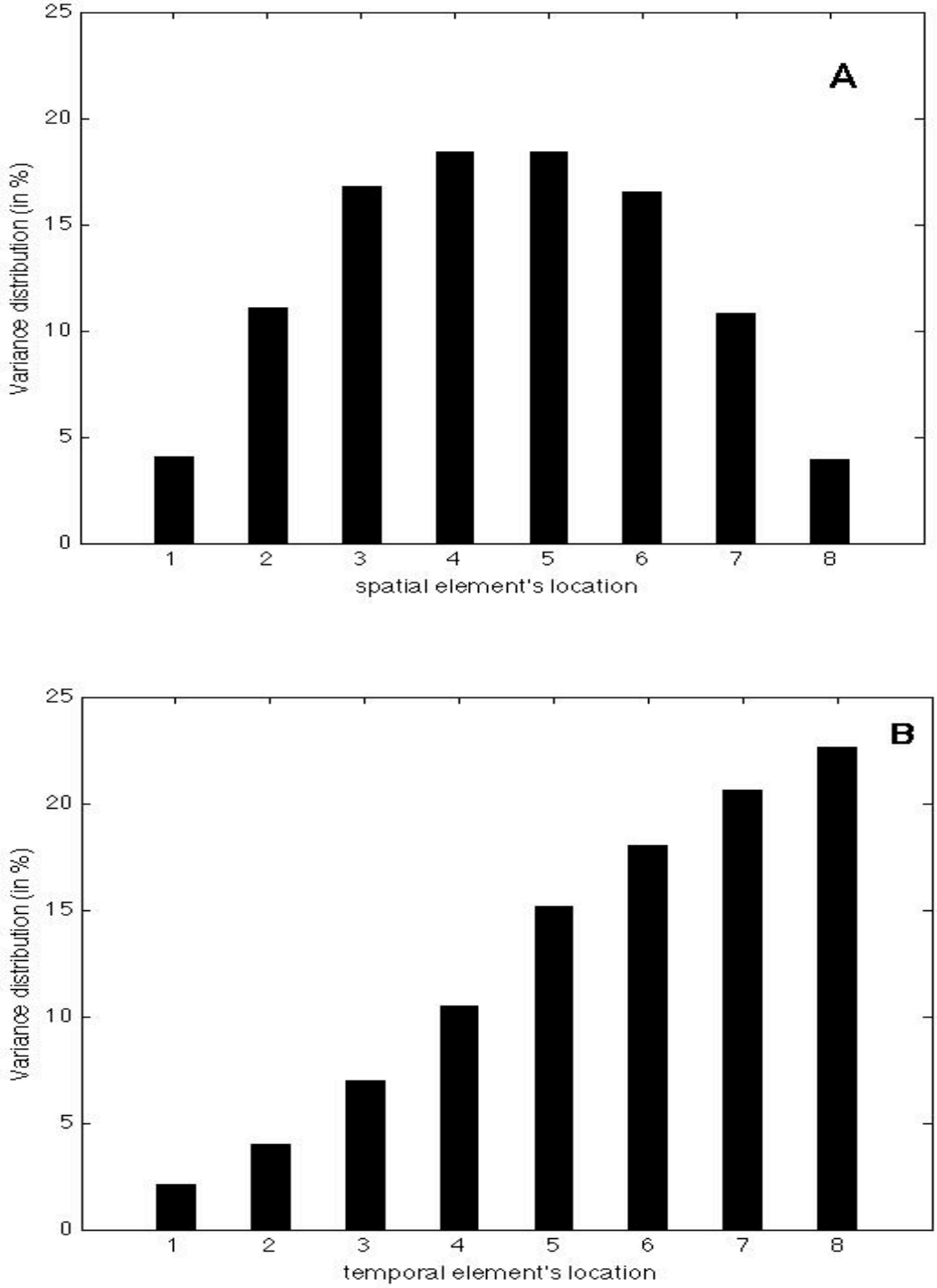
A
Variance distribution (in %)
spatial element's location
B
Variance distribution (in %)
temporal element's location

Figure 6

Table 1: Spatial and temporal characteristics of the target configuration.

	Dot location (cm)	*Spatial intervals (cm) between 2 consecutive dots*	*Temporal intervals (ms)*
Dot 1	4.40		
Dist. 1		7.46	746
Dot 2	11.86		
Dist. 2		3.82	382
Dot 3	15.68		
Dist. 3		10.80	1080
Dot 4	26.48		
Dist. 4		11.20	1120
Dot 5	37.68		
Dist. 5		7.46	746
Dot 6	45.14		
Dist. 6		7.46	746
Dot 7	52.60		
Dist. 7		4.00	400
Dot 8	56,60		