ORAL PAPER

Dynamic variability in mnemic systems: a way to study the consolidation process

B. Berberian • M. D. Giraudo

Keywords Memory · Variability · Consolidation

Background

Classically, memory has been defined as the preservation in time of internal representations called mental images (Cooper 1976; Finke and Kosslyn 1980; Finke and Kurtzman 1981; Shepard 1978). An extensive body of literature has been devoted to understanding the processes allowing for stabilization of these mental images. It is noteworthy that nearly all these studies have presented the consolidation process as a freezing process, in other terms, it has been considered that organization of the information has not been really continuous in time. Hence, in a certain way, the whole concept of memory turned to be considered as 'rigid'. In this perspective, within-subject variability of the motor output can be seen as the result of the noise present in the system and, consequently, as a random process without temporal structure.

However, these considerations appear inconsistent with previous investigations that have examined perceptual and mnesic processes from a dynamical perspective (Bartlett 1932; Burnham 1903; DeCamp 1915; Hebb 1949; Köhler 1947; Lashley 1950; Loeb 1901, 1973). In addition, empirical evidences have revealed that this variability cannot be considered as the result of minor changes (Portugali 1996), differences in detail (Polster et al. 1991) or result of the noise present in the system (Giraudo and Pailhous 1994). Finally, the idea that variability is to be considered as simple noise in the system is more an exception than the rule itself, in light of recent contributions in the field of motor control. Such a hypothesis is supported in light of the temporal structure differentiating variability from white noise (Collins and Deluca 1993; Gilden et al. 1995; Newell et al. 1995; Slifkin and Newell 1998; Gilden 2001).

Inspired by these previous studies, Giraudo and Pailhous (1994, 1999) analyzed the stabilization process of an image in memory using a time-series analysis. Their results showed that two independent processes are simultaneously involved in the formation of visuospatial memories: One process is responsible for the accuracy of image generation, and a second process is responsible for image variation. This second process is characterized by the presence of a temporal structure independent to the task characteristics. In particular, a same level of variability, referred to as "resolution threshold", is reached.

First, these results appear not to be consistent with the notion of variability as simply resulting from noise in the system, with the notion of consolidation as simple fixation of the mental image properties in a second part. Taken together, these findings support the hypothesis that variability is an intrinsic property of the mnesic system. Our approach is based on the assumption that the study of this variability is necessary to understand how the system evolves in time, and, thus, to understand how one can consolidate a mnesic image.

Here, the goal of the experiments is to examine the organization of information in memory with the underlying hypothesis that this organization contributes to the consolidation of mental images. We focus on the effects of image complexity on the variability of repeated reproduction, the hypothesis being that the consolidation process allows reducing the number of degrees of freedom to be controlled simultaneously.

Method

Three groups of participants (24 subjects by group) are involved in three different visuo-spatial memory tasks.

M. D. Giraudo (✉) • B. Berberian
Faculté des Sciences du Sport,
Universitéde la Méditerranée, Marseille, France
e-mail: marie-dominique.giraudo@univmed.fr

Participants were instructed to first memorize and then reproduce successively a configuration of dots 40 times. In each experiment, three different levels of complexity are tested, the level of complexity being defined by the number of dot which composed the target configuration (7, 12 or 17 dots).

In the first experiment, the target configuration was presented during 5 s and the participants were told to memorize this configuration. Then, the pattern was removed and the task of the subjects was to reproduce the configuration as accurately as possible. Each subject performed the task 40 times. During the 20 first trials, subjects studied the pattern 20 times, and between each presentation performed the task. From trial 21 to trial 40, the subject performed the task 20 times successively without renewed presentation. As explained by Schöner (1989), we observe in this first experiment the extrinsic dynamic of the system since an external parameter (the target configuration) has constrained the system.

In the second experiment, the subjects saw the target during the first trial and were then required to reproduce it twenty times successively from memory. From trail 21 to trial 40, subject saw and reproduced the target at each trial. We considered this condition as a way for observing the intrinsic dynamics of the system since, in this condition, the external constraint is absent.

Finally, in the experiment 3, the procedure was the same than in the first experiment but the target configuration was composed of simple forms. Simple forms refer to the notion developed by the Gestalt Theory (Koffka 1935; Köhler 1969; Wertheimer 1923) and are characterized by metric redundancy (distance and angular). In other terms, the target configuration corresponds to a pre-structured configuration.

Results

Results have been analyzed in terms of accuracy (that is the discrepancy between the target pattern and each successive reproduction), and in terms of variability (that is the discrepancy between each successive reproduction regardless of the target). In the first experiment, i.e. in the one addressing extrinsic dynamics, the results revealed that as target complexity increased, the number of trials necessary to reach a steady state also increased. Nevertheless, the level of variability reached in steady state was significantly equivalent in all three levels of complexity. Moreover, this relaxation time is accompanied by a re-organization of the image (simplification of the perceived configuration and development of relations between dots).

In the second experiment, i.e. in the one exploring intrinsic dynamics, the relaxation time was almost instantaneous in the three conditions and the resolution levels reached were equivalent of these obtained in the first experiment. This relaxation time is accompanied by a massive simplification of the configuration. In such a way the configuration reproduced by the subject represents a "good forms" in a Gestalt perspective.

In the third experiment, i.e. when the target configuration is a simple form, the stabilization was instantaneous and the subjects successfully reproduced the pre-structured configuration with high accuracy after the first target presentation in the three levels of complexity. The level of resolution was again similar to those obtained during the two first experiments.

Conclusions

The results of these experiments clearly reveal that:

(1) Variability is an intrinsic property of the mnesic system. Indeed, variability and accuracy are completely independent in terms of dynamics. Moreover, neither the number of dots nor the degree of simplicity of target configuration changed the level of resolution of the mental image.

(2) Consolidation leads to organize the information. This organization is illustrated by a simplification of the target configuration and by the creation of relation between the different elements. When this organization is pre-existent, in an internal way (intrinsic dynamics, experiment 2), or in an external way (pre-structured target, experiment 3), this consolidation process is almost instantaneous. Our findings provide evidence that the consolidation process is an information structuration process.

(3) The role of organization of information is to reduce the number of degrees of freedom to be controlled simultaneously in the target configuration (Bernstein 1967). Indeed, the simplifications that emerge appear to be characterized by an information redundancy and, concomitantly, as indicated by Tuller et al. (1982) to be "linking elements reduces the number of degrees of freedom that must be controlled independently" (p. 265).

(4) Finally, the memorized configuration results from the competition between an environmental constraint and an internal one (Schöner 1989; Zanone and Kelso 1992). The environmental constraints tend to attract the configuration memorized toward the target configuration whereas the internal dynamics (or natural attractors) tends to attract the configuration memorized toward the simple form. The time needed for mnesic content consolidation will be directly dependent on this level of constraints. The smaller the environmental constraints, the faster the consolidation process. At the same time, the properties of the mnesic content are also directly dependent on the power of environmental constraints. The bigger the environmen-

tal constraints, the smaller be the simplifications of the mnesic content. Oppositely, the smaller the environmental constraints, the bigger the simplifications of the memorized content.

References

Bartlett F (1932) Remembering: a study in experimental and social psychology. Cambridge University Press, Cambridge

Bernstein N (1967) The co-ordination and regulation of movements. Pergamon, Oxford

Burnham WH (1903) Retroactive amnesia: illustrative cases and a tentative explanation. Am J Psychol 14:382–396

Collins JJ, Deluca CJ (1993) Open-loop and closed-loop control of posture: a random walk analysis of center-of-pressure trajectories. Exp Brain Res 95:308–318

Cooper LA (1976) Demonstration of a mental analog of an external rotation. Percept Psychophys 19:296–302

DeCamp JE (1915) A study of retroactive inhibition. Psychol Monographs 19 (4, whole No. 84)

Finke RA, Kosslyn SM (1980) Mental imagery acuity in the peripheral visual field. J Exp Psychol Hum Percept Perform 6:244–264

Finke RA, Kurtzman HS (1981) Area and contrast effects upon perceptual and imagery acuity. J Exp Psychol Hum Percept Perform 7:825–832

Gilden DL (2001) Cognitive emission of 1/f noise. Psychol Rev 43:23–52

Gilden DL, Thornton T, Mallon MW (1995) 1/f noise in human cognition. Science 267:1837–1839

Giraudo MD, Pailhous J (1994) Distortions and fluctuations on topographic memory. Memory Cognit 22:14–26

Giraudo MD, Pailhous J (1999) Dynamic instability of visuospatial images. J Exp Psychol Hum Percept Perform 25(6):1495–1516

Hebb DO (1949) The organization of behaviour: a neuro-psychological theory. Wiley, New York

Koffka K (1935) Principles of gestalt psychology. Harcourt Brace, New York

Köhler W (1947) Gestalt psychology. Liveright, New York

Köhler W (1969) The task of gestalt psychology. Princeton University Press, Princeton, pp 60–62

Loeb J (1973) Comparative physiology of the brain and comparative psychology. Arno Press, New York (Original work published 1901)

Newell KM, Gao F, Sprague RL (1995) The dynamics of finger tremor in tardive dyskinesia. Chaos 5:43–47

Polster MR, Nadel L, Schacter DL (1991) Cognitive neuroscience analyses of memory: a historical perspective. J Cognit Neurosci 3:95–116

Portugali J (1996) Inter-representation networks and cognitive maps. In: Portugali J (eds) The construction of cognitive maps. Kluwer, Norwell, pp 11–43

Schöner G (1989) Learning and recall in a dynamic theory of coordination patterns. Biol Cybern 62(1):39–54

Shepard RN (1978) The mental image. Am Psychol 33:125–137

Slifkin A, Newell KM (1998) Performance variability: looking for information in noise. Current Directions in Psychological Science

Tuller B, Turvey MT, Fitch H (1982) The Bernstein perspective: II. The concept of muscle linkage or coordinative structure. In: Kelso JAS (ed) Human motor behavior: an introduction. Lawrence Erlbaum Associates, Hillsdale

Wertheimer M (1923) Untersuchungen zur Lehre der Gestalt, II. Psychol Forsch 4:301–350

Zanone PG, Kelso JA (1992) Evolution of behavioral attractors with learning nonequilibrium phase transitions. J Exp Psychol Human Percept Perform 18(2):403–421