



## Research report

Effects of pattern redundancy and hierarchical grouping on global–local visual processing in monkeys (*Cebus apella*) and humans (*Homo sapiens*)Carlo De Lillo<sup>a,\*</sup>, Milena Palumbo<sup>a,b</sup>, Giovanna Spinozzi<sup>b</sup>, Giuseppe Giustino<sup>b</sup><sup>a</sup> School of Psychology, University of Leicester, Henry Wellcome Building, Lancaster Road, Leicester LE1 9HN, UK<sup>b</sup> Istituto di Scienze e Tecnologie della Cognizione, Consiglio Nazionale delle Ricerche (CNR), Via Ullisse Aldrovandi 16/B, 00197 Rome, Italy

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## ABSTRACT

Using a Matching-To-Sample (MTS) procedure we assessed the effects of stimulus redundancy, defined on the basis of the information–theory approach to shape goodness proposed by Garner (1974) [20], and grouping on the processing of hierarchical visual patterns in capuchin monkeys and humans. In a first experiment, the MTS performance of both capuchin monkeys and humans benefitted from stimulus redundancy. Moreover, a local advantage in capuchins was observed with visual patterns that required grouping at both global and local level. In a second experiment we eliminated the requirement to group at the local level. This was done to determine if the effects of redundancy would have been evident in condition more similar to those used in previous studies of global–local processing in a comparative context. The benefits of stimulus redundancy emerged again in both species but were confined to local processing in monkeys and to global processing in humans. A local advantage was observed in both species. In a third experiment, the reduction of the size of the stimuli and the increase of the quantity of the local elements produced a shift to global dominance in humans but the local dominance in monkeys was preserved. The implications of these results are discussed in relation to other similarities and differences in higher visual functions in humans and monkeys.

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## 1. Introduction

There is a substantial amount of visual neuro-scientific research on non-human primates [49] carried out assuming that it is possible to use data from humans and monkeys interchangeably. The assumed similarity of the visual system of primates has sometimes induced researchers to report electrophysiological data on monkeys alongside human behavioural data (see [35] for a recent review).

The assumption that non-human primates are a suitable model of human visual processes is justifiable on a number of grounds. In all diurnal primates, vision is the dominant sensory modality [19]. Moreover, the physiology of low level vision is similar in monkeys and humans [13,26] who also present similar contrast sensitivity functions to different spatial frequencies [12,36]. Moreover, given their close taxonomic distance, it could prove possible to map brain homologies in humans and monkeys. The mapping of homologies in humans and monkeys is particularly meaningful when carried out in relation to the neural bases of low level visual functions [34] but the homologies in the visual systems of humans and monkeys probably pertain to higher cortical visual pathways as well [49].

Notwithstanding these similarities, there is a growing body of literature indicating that there may be some differences between monkeys and humans in other aspects of visual cognition. For example, there is evidence that capuchin monkeys segment complex visual patterns differently from humans. Spinozzi et al. [44] compared performance of these two species in a Matching-To-Sample (MTS) task requiring the subjects to identify which among different stimulus parts presented as comparison stimuli, belonged to a whole pattern presented as the sample. The stimulus parts were formed by a number of elements that could be either connected on the basis of a variety of grouping principles (“grouped parts”) or unconnected (“ungrouped parts”). Humans showed a clear advantage for identifying the grouped parts. By contrast, monkeys showed a remarkable advantage for identifying the parts when they were ungrouped.

One possible explanation for the interspecies differences observed in the above study is that they may be due to a relative preponderance of different grouping processes in monkeys and humans. Evidence from the literature on human perception indicates that classic gestalt grouping principles [14] might vary in their attentional demands [3,4,23,24,29,32,41]. It is therefore possible that humans and non-human primates may derive different perceptual representations of the same patterns due a different bias towards the use of given grouping cues rather than others. The study by Spinozzi et al. [44] was not explicitly designed

\* Corresponding author. Tel.: +44 0116 229 7193; fax: +44 0116 229 7196.  
E-mail address: [cdl2@leicester.ac.uk](mailto:cdl2@leicester.ac.uk) (C. De Lillo).

to evaluate this possibility. However, it featured either closed or open shapes in different stimulus conditions. Interestingly, closure proved an important factor in humans, who performed at a significantly higher level of accuracy in trials with closed shapes. By contrast, monkeys did not show this effect.

Another study addressed more specifically the issue of the relative weight of different organizational principles in humans and capuchin monkeys [47]. That study featured a comparative investigation of the relative use of proximity, shape similarity and orientation as perceptual grouping cues using a MTS task which required grouping and figure-ground segregation. Both monkeys and humans were sensitive to all these grouping cues. Nevertheless, the relative importance of each of these cues was different in the two species. Humans performed more efficiently in conditions requiring grouping by proximity than conditions requiring grouping by similarity of shape or element orientation. By contrast, capuchins processed equally well proximity and shape similarity groupings but made more errors when required to group on the basis of the orientation of figural elements (see Fig. 3 in [47]).

Grouping by proximity has been proposed as an explanation of cognitive differences in primates [2,16,18,42]. In a number of different contexts and cognitive domains it has been pointed out that baboons find it difficult, and attention demanding, to group spatially separated elements of a compound pattern into a coherent whole [11]. These findings suggest that humans may be less vulnerable than non-human primates to the spatial separation of elements of a visual scene and that this could explain, in an unsuspected way, a number of interspecies differences in cognition (see [17] for a discussion). Thus, a complex pattern of similarities and differences has been reported in the relative use of organizational principles in primates.

On the other hand, there is evidence from studies on pattern recognition that non-human primates are just as sensitive as humans are to the organizational properties of stimulus components. In a MTS study with different conditions where the arrangement of the component parts of the comparison stimuli was manipulated, De Lillo et al. [9] found striking similarities between the way in which capuchin monkeys and humans encoded the spatial relations between stimulus parts. The matching performance of both species was not affected by a global rotation of the whole stimulus, which preserved the internal relationship between the parts. By contrast, variations in the arrangement of local features of stimuli, obtained by scrambling their component parts, produced a dramatic decrement of performance in both humans and monkeys. The above study used jigsaw-like shapes as stimuli in order to minimise the possible use of verbal description by humans and to control for the level of familiarity in the two species.

Another study assessed spontaneous manipulations of stimulus cards with original or manipulated images of schematic faces and geometric patterns in capuchin monkeys [1]. It was found there that capuchins prefer stimuli where the regularity and symmetry of the original stimulus is preserved. A very low preference was expressed for cards where the regularity and symmetry of the patterns they depicted was compromised by scrambling their component parts.

Although this study [1] indicates a spontaneous preference for regular and/or symmetrical patterns in monkeys, it is not clear if this is because they find symmetrical patterns easier to process. In fact, Schrier et al. [43] tested stump-tailed monkeys (*Macaca arctoides*) on discrimination problems with different levels of figural symmetry as the experimental variable and found that discrimination performance was not facilitated by the symmetry of the patterns. In the study by Schrier et al. [43], the different levels of symmetry were obtained on the basis of Garner's [20] model of figural goodness that, given its importance for the present study, will be described in some detail below.

In an attempt to quantify pattern goodness within a gestalt tradition, Garner [20] gave a definition of goodness in terms of redundancy. According to Garner, the perceived goodness of a given pattern is inversely related to the size of the set of stimuli obtained by applying reflection and/or 90° rotation to that pattern. The reflection and rotation of good patterns generates small sets, making these patterns highly redundant. By contrast, poor patterns generate large sets and are characterised by a low level of redundancy. For example, a circle or a cross would be highly redundant shapes as their 90° rotation or reflection results in the same pattern. By contrast, a more irregular shape, such as a polygon containing several different angles, would be less redundant since it would produce different patterns following its rotation and/or reflection. Garner confirmed the relationship between redundancy and perceived goodness empirically by asking human participants to judge the relative goodness of dot patterns. Patterns from small equivalent sets (highly redundant) were rated as very good shapes, whereas patterns from large equivalent sets (less redundant) were rated as poorer shapes [22]. Follow up studies have shown that good patterns are encoded more efficiently [21], are easier to maintain in memory [6] and to sort into categories [7].

The notion of redundancy has proved of extreme importance in human cognitive psychology [21,22,25,37–39] and it is possible to envisage the possible adaptive value, for example in terms of information management, of the ability to exploit the redundancy of stimuli that need to be processed and encoded. From a comparative standpoint it is thus intriguing that the results obtained by Schrier et al. [43] should indicate that monkeys who share with us a sophisticated visual and cognitive system may be less sensitive than humans to factors associated with stimulus redundancy. In fact, the stump-tailed monkeys used by Schrier et al. [43] were given a series of pattern discrimination problems using stimuli directly derived from Garner and Clement [22]. The stimuli consisted in dots arranged within a 3 × 3 matrix. Different discriminations featured stimuli of a given level of redundancy (or pattern goodness). The level of redundancy of the stimuli was defined according to Garner and Clement in terms of the size of rotation-and-reflection equivalence set they generated. The monkeys' learning and response latency were not faster for discriminations involving more redundant patterns (good patterns) compared to those with a lower level of redundancy (poor patterns). This contrasts with results obtained with humans using similar stimuli and paradigms [20]. A different sensitivity to redundancy between humans and other primates could therefore indicate an important peculiarity of the human cognitive systems in relation to its ability to efficiently manage information processing and storage.

Further assessments of the sensitivity of non-human primates to this factor would therefore be of value for this reason and for the other important reasons outlined below.

Navon [40] demonstrated that humans have a tendency to process the global form of hierarchical visual patterns, where a global shape is formed by the spatial arrangement of more local elements. Humans typically process global shapes faster and better than the shape of their local constituents and show an asymmetrical global-to-local interference. A number of studies carried out on non-human primates, by contrast, indicate that monkeys find it easier to process the shape of the local elements [8,10,16,46]. Although the extraction of the global shape of this type of stimuli is likely to require some form of grouping, it is possible that differences, albeit small, in the relative use of grouping cues as discussed above could explain at least some of the interspecies differences observed in this domain. Importantly, all the shapes used so far in studies where human and non-human primates have been compared, are highly redundant forms (circles, squares, diamonds, crosses etc.). One of the strengths of Navon's paradigm is that when using hierarchical stimuli it is possible to use the same

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